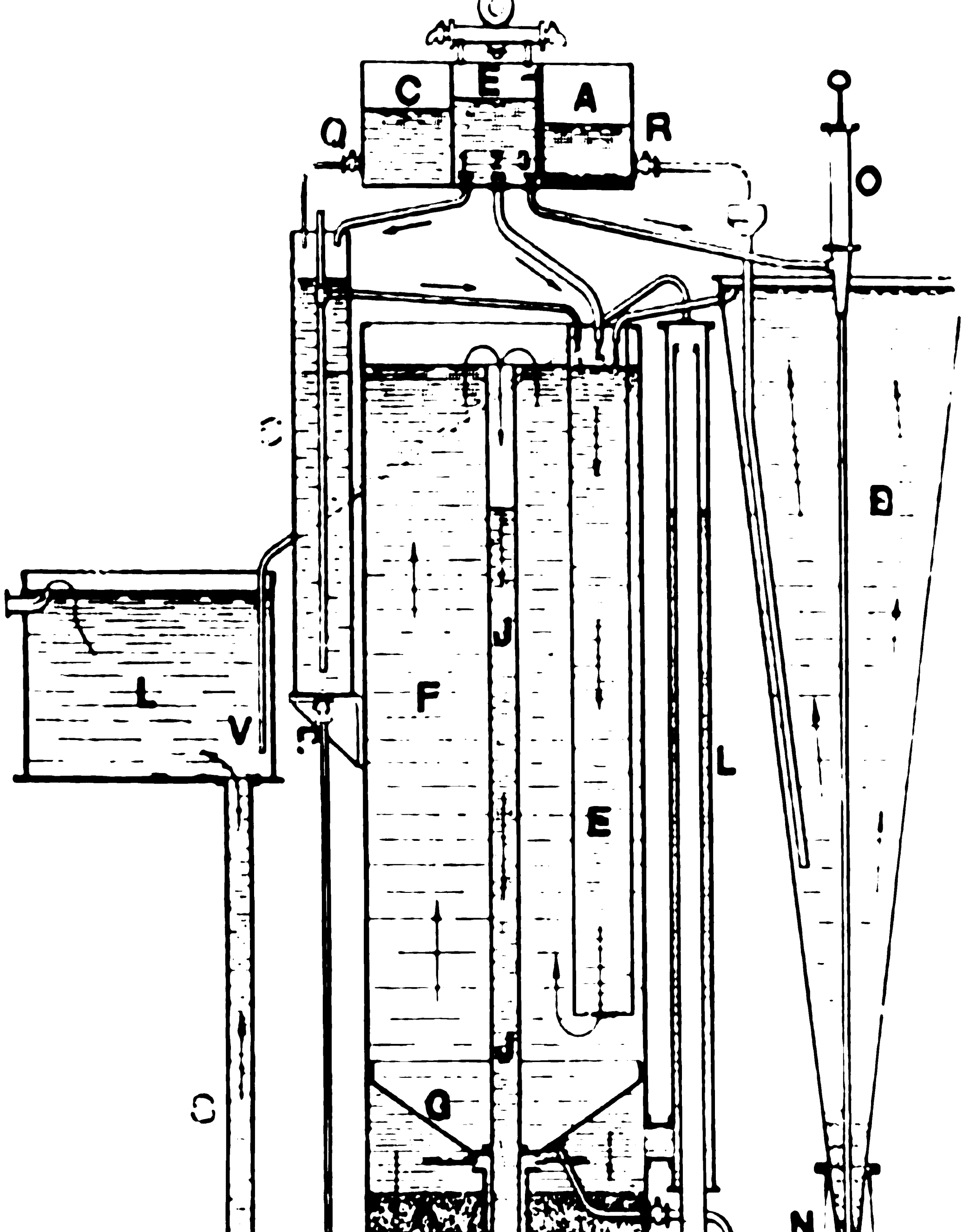

Domestic sanitation and plumbing

A. Herring-Shaw

DOMESTIC SANITATION AND PLUMBING

DOMESTIC SANITATION AND PLUMBING

A TREATISE OF THE MATERIALS, DESIGNS, AND METHODS USED IN SANITARY ENGINEERING MANUFACTURE, JOINTING AND FIXING OF PIPES, SANITARY FITTINGS, ETC.; REMOVAL OF WASTE MATTER; WATER SUPPLY; HOT-WATER SERVICES; HEATING; VENTILATION, ETC.

BY A. HERRING-SHAW, R.P.C.

Associate, Royal Sanitary Institute; Victoria University Sanitary Certificate; Honours Silver Medallist, City and Guilds of London Institute; Assistant Lecturer in Sanitary Engineering, Victoria University, Manchester; Lecturer, etc., and Chief Assistant in the Municipal and Sanitary Engineering Department, School of Technology, Manchester

PART II

WATER SUPPLY; DOMESTIC HOT-WATER SERVICES; WARMING AND VENTILATION OF BUILDINGS

WITH TWO HUNDRED AND SIXTY-FOUR ILLUSTRATIONS

GURNEY AND JACKSON
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PREFACE

THE encouraging reception which Part I., *Domestic Sanitation*, has met with, and the many eulogistic communications received from all parts of the United Kingdom and from abroad, have caused the author to hope that the scope and usefulness of Part II. will be proved in like manner.

The important principles and details throughout the work are illustrated by diagrams, drawings, and sketches, where possible.

In dealing with the various calculations in the hydraulics and heating sections, it has been the author's endeavour to encourage readers to deduce results from first principles. A wider range of action and greater elasticity is discovered with the careful use of known factors than with formulæ the construction of which is often but imperfectly understood.

The author's thanks are due to those manufacturers who have kindly lent electros for illustration purposes.

A. HERRING-SHAW.

MUNICIPAL SCHOOL OF TECHNOLOGY,
MANCHESTER, 1910.

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CHAPTER I

SOURCE OF WATER SUPPLIES—THE RAINFALL—MEASUREMENTS OF RAINFALL, ETC.

ALL water supplies have their origin in the rainfall. Whether the particular positions from which the water is obtained be under ground or above ground, the water that collects or accumulates in such positions is the direct result of the rainfall.

Formation of Rain.—This is due to evaporation of water from all moist surfaces, especially from large tracts of water, and its subsequent condensation owing to a change of atmospheric conditions and also to the influence of local surroundings.

Evaporation is going on continuously from all moist surfaces under practically all conditions of the atmosphere. The rate of evaporation and consequently the amount of water-vapour produced in a given time, is influenced chiefly by the temperature of the atmosphere, the sun's rays, and the velocity of the air movements, *i.e.* winds. Evaporation is most rapid in the equatorial regions of the great oceans, where the temperature is greatest. The air movements are constantly carrying away the water-vapour into other regions, and thus maintaining in a moderately dry state the air in the vicinity of the evaporation. Hence the winds have a considerable effect upon the rate of evaporation, by displacing the moisture-laden air by currents of drier air.

The term "relative humidity" is used to indicate the ratio

between the amount of water-vapour actually present and the quantity required to saturate the air at a given temperature and pressure.

The "degree of saturation" or "relative humidity" of the air may be ascertained by means of the "hygrometer," an instrument which embodies the principle of the variation of evaporation due to variation of temperature and the amount of water-vapour held in the air. It will be seen from Fig. 1 that the hygrometer consists of two thermometers fixed from four to six inches apart. The bulb of one thermometer is covered with a piece of muslin from which all the natural wax has been extracted; several strands of muslin are permitted to hang from the bulb-covering and dip into distilled water held in a small glass vessel. The water passes by capillarity up the threads and keeps the mercury bulb constantly wetted. This thermometer is usually described as the wet bulb thermometer. If the temperatures indicated by the two thermometers, *i.e.* the "wet bulb" and "dry bulb" respectively, be observed at different times, it will be found that the dry bulb "reading" is invariably higher, and never less than, the "reading" of the wet bulb; although the same temperature may be recorded by the dry bulb on several occasions, yet the record on the wet bulb scale may vary on each occasion. This variation is caused by the rate of evaporation being influenced by the quantity of water-vapour contained in the air. When the air is comparatively dry, evaporation of water from the muslin covering of the wet bulb goes on rapidly, heat is extracted from the mercury, and its temperature is therefore lowered. If the air contains a considerable quantity of water-vapour per cubical unit, the rate of evaporation is much slower, and in consequence the mercury records a higher temperature.

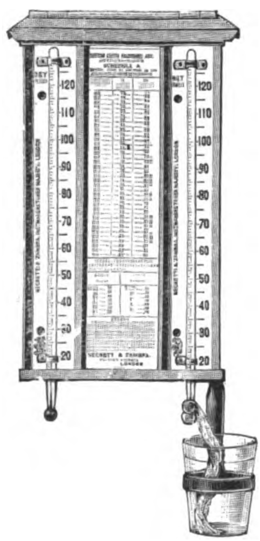

FIG. 1.— Negrett and Zambra's Hygrometer.

When the air is saturated with water-vapour a slight

decrease of temperature will cause condensation to occur. This condition of the atmosphere is known as the "dewpoint."

To determine the "relative humidity" and the "dewpoint," Glaisher's factors are necessary.

Weight of Vapour required for Saturation for each degree Fahrenheit from 10° *to* 100°.

Degrees Fahr.	Weight of Vapour in grains per cubic foot.	Degrees Fahr.	Weight of Vapour in grains per cubic foot.	Degrees Fahr.	Weight of Vapour in grains per cubic foot.
10	0·84	40	2·86	70	8·01
11	0·88	41	2·97	71	8·27
12	0·92	42	3·08	72	8·54
13	0·96	43	3·20	73	8·82
14	1·00	44	3·32	74	9·10
15	1·04	45	3·44	75	9·39
16	1·09	46	3·56	76	9·69
17	1·14	47	3·69	77	9·99
18	1·19	48	3·82	78	10·31
19	1·24	49	3·96	79	10·64
20	1·30	50	4·10	80	10·98
21	1·36	51	4·24	81	11·32
22	1·42	52	4·39	82	11·67
23	1·48	53	4·55	83	12·03
24	1·54	54	4·71	84	12·40
25	1·61	55	4·87	85	12·78
26	1·68	56	5·04	86	13·17
27	1·75	57	5·21	87	13·57
28	1·82	58	5·39	88	13·98
29	1·89	59	5·58	89	14·41
30	1·97	60	5·77	90	14·85
31	2·05	61	5·97	91	15·29
32	2·13	62	6·17	92	15·74
33	2·21	63	6·38	93	16·21
34	2·30	64	6·59	94	16·69
35	2·39	65	6·81	95	17·18
36	2·48	66	7·04	96	17·68
37	2·57	67	7·27	97	18·20
38	2·66	68	7·51	98	18·73
39	2·76	69	7·76	99	19·23
...	...	...	...	100	19·84

To find the relative humidity or percentage of saturation of the atmosphere, it is necessary to find the dewpoint, *i.e.*, the

temperature at which the atmosphere would be saturated, with the amount of vapour it contained at the time of observation.

Glaisher's Factors.

Reading of Dry Bulb. Fahr. degrees.	Factor.	Reading of Dry Bulb. Fahr. degrees.	Factor.	Reading of Dry Bulb. Fahr. degrees.	Factor
10	8·78	40	2·29	70	1·77
11	8·78	41	2·26	71	1·76
12	8·78	42	2·23	72	1·75
13	8·77	43	2·20	73	1·74
14	8·76	44	2·18	74	1·73
15	8·75	45	2·16	75	1·72
16	8·70	46	2·14	76	1·71
17	8·62	47	2·12	77	1·70
18	8·50	48	2·10	78	1·69
19	8·34	49	2·08	79	1·69
20	8·14	50	2·06	80	1·68
21	7·88	51	2·04	81	1·68
22	7·60	52	2·02	82	1·67
23	7·28	53	2·00	83	1·67
24	6·92	54	1·98	84	1·66
25	6·53	55	1·96	85	1·65
26	6·08	56	1·94	86	1·65
27	5·61	57	1·92	87	1·64
28	5·12	58	1·90	88	1·64
29	4·63	59	1·89	89	1·63
30	4·15	60	1·88	90	1·63
31	3·70	61	1·87	91	1·62
32	3·32	62	1·86	92	1·62
33	3·01	63	1·85	93	1·61
34	2·77	64	1·83	94	1·60
35	2·60	65	1·82	95	1·60
36	2·50	66	1·81	96	1·59
37	2·42	67	1·80	97	1·59
38	2·36	68	1·79	98	1·58
39	2·32	69	1·78	99	1·58
...	...	...	...	100	1·57

To use Glaisher's factors for finding the dewpoint:—

Rule.—Subtract the reading of the wet bulb thermometer from the reading of the dry bulb. Multiply the difference by the factor opposite the dry bulb in the preceding table, and subtract the product from the reading of the dry bulb, and the result will be the dewpoint.

Example—

Reading of dry bulb = 68
„ wet bulb = 60

Factor opposite reading of dry bulb = 1·79

$$\text{Dewpoint} = 68 - ((68 - 60) \times 1{\cdot}79)$$
$$= 68 - 14{\cdot}32$$
$$= 53{\cdot}68$$

Having found the dewpoint, the actual amount of water-vapour present in a known volume of the atmosphere may be obtained from the table previously given, of weights of vapour constituting saturation for each degree Fahr.

The relative humidity will then be the ratio between the amount of vapour actually present, and the amount required to saturate the atmosphere at the temperature indicated by the dry bulb.

It is generally expressed as a percentage of saturation :—

	°F.		Grains.
∴ Amount of vapour per cubic foot required to saturate at	53·68	=	4·65
Amount of vapour per cubic foot required to saturate at	68·00	=	7·51

$$\text{Relative humidity} = \frac{4{\cdot}65 \times 100}{7{\cdot}51} = 62 \text{ per cent. of saturation.}$$

Water-vapour is invisible, and its density is less than that of air. Immediately it is formed it rises to a comparatively high altitude and is carried by air currents into other regions. There it is formed into clouds, owing, it is said, to the presence of minute particles of volcanic dust in the air, each particle of dust forming a collecting centre to which one or more molecules of water-vapour are attracted and subsequently become condensed. The condensed water-vapour becomes visible, and when a saturated condition of the atmosphere obtains, a portion of the condensed vapour falls in the form of rain.

Variation of the amount of rainfall throughout the United Kingdom is due principally to the direction of the prevailing winds, and to the contour and relative position of each part of the Kingdom.

High land in the form of hills and mountains has a great influence upon the rainfall of the district in which it is

situated. Again, inland districts, especially those that are comparatively low-lying, have not the same rainfall as districts of a hilly character nearer to the sea.

The prevailing winds that pass over our islands, are from the west and the south-west. The heaviest rainfall is experienced along the west coasts of Ireland, England, Wales, and Scotland, particularly in the hilly and mountainous districts.

The moisture-laden air is carried by the prevailing winds across the Atlantic Ocean, and when it reaches the west coast it is diverted by the hills and mountains to higher and colder altitudes. The combined effect of existing lower temperatures at the higher altitudes, the loss of heat due to a reduction of pressure and the consequent expansion of the water-vapour, and the cooling effect of the mountain surfaces owing to radiation of heat from the clouds thereto, brings about a saturated condition of the atmosphere, when a portion of the water-vapour falls as rain.

The amount of variation throughout the country is considerable. The highest records have been obtained at Seathwaite in Cumberland, and on the north-west coast of Wales, and Scotland; whilst the lowest records have been registered in certain of the midland counties and on the east coast.

The rainfall in this country varies from 15 ins. to 140 ins. per annum.

The measurement of the rainfall of the British Isles is necessary for reasons other than those of a meteorological character. The work of large undertakings that have involved the expenditure of millions of money, and which are now supplying cities and towns with water, has been greatly facilitated owing to the systematic measurement of the amount of rain falling within the districts in which they are situated.

An accurate record is kept of the rainfall in the various parts of these Isles. The figures may be obtained from Symond's *British Rainfall*.

The apparatus used for measuring the rainfall is known as a "rain-gauge." There are several types of this apparatus, one of which is self-recording, whilst another requires to have the stored rain measured in a graduated cylinder. Fig. 2 shows a part section and view of a rain-gauge *in situ*. The gauge is cylindrical in shape, and is usually made of copper; the top, C,

is detachable, and fits into a groove formed in the top of the lower cylinder. The funnel-shaped interior of C conveys the rain-water into the receiver D. The diameter and trueness of the rim A B must be accurately determined, and its shape must be maintained after the gauge is fixed. The glass cylinder E is graduated to indicate hundredths of an inch. It is calibrated in conjunction with the rim A B, and may only be used for measuring the rain-water collected in the gauge from which the calibrations were made.

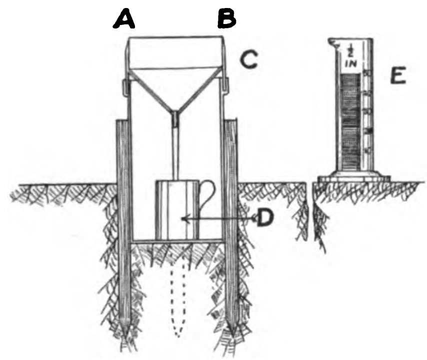

Fig. 2.—Rain-gauge *in situ*, with Measuring Cylinder.

The sizes of rain-gauges are determined by the diameters of the rims, and are in general practice 5 ins., 8 ins., and 12 ins. The 8-in. gauge is commonly used.

Care is required when fixing rain-gauges, to prevent them from being disturbed by either the wind or the intrusion of animals; also, the position should be an open one, with no obstructions such as walls, trees, or high ground, which would act as screens and prevent the rain-water from freely entering the gauge.

Oak stakes 1½ ins. square and about 18 ins. long are used for securing the gauge to the ground. The rim of the gauge is usually fixed 1 ft. above the ground.

In most cases gauges are read each day at 9 A.M., but in some cases weekly and even monthly readings are taken where a number of gauges are fixed in widely scattered positions on a watershed.

The following table is taken from the annual report in connection with the Godlee Observatory, School of Technology, Manchester. It will be observed that the greatest fall of rain occurs when the wind is blowing from the south-west and west, and that the barometric readings are lower on these occasions than during fine days.

July 1909.

Day.	Mean Barometer reduced to 32° F.	Temperature, in Shade.		Wind. Direction.	Estimated Amount of Cloud.	Rain.	Remarks on the Weather.
		Maximum.	Minimum.				
	Inches.	° F.	° F.			Inch.	
1	30·008	63·3	47·0	N.E.	7·5	...	Dull till noon, then fine.
2	29·996	73·3	49·6	S.W.	2·3	...	Fine, warm.
3	29·816	72·3	56·8	S.W.	10·0	0·195	Some showers.
4	29·795	68·6	55·6	W.N.W.	8·5	0·002	Generally overcast.
5	29·773	62·5	56·2	W.S.W.	10·0	0·085	Overcast, threatening.
6	29·336	60·0	54·0	W.S.W.	10·0	0·141	Showery.
7	29·433	62·4	52·9	W.N.W.	8·5	0·092	Showery.
8	29·765	67·0	55·0	N.W.	3·5	...	Cloudy to fine.
9	29·719	67·5	53·4	W.	9·5	0·581	Very gloomy, rain after 4 P.M.
10	29·447	62·0	53·9	W.N.W.	6·8	0·128	Cloudy to fine.
11	29·660	59·2	52·2	W.N.W.	10·0	...	Overcast.
12	29·854	64·2	51·5	N.W.	5·8	0·091	Fine.
13	29·823	66·8	54·4	S.W.	10·0	0·025	Rain at times.
14	29·857	65·2	56·5	W.	9·5	0·014	Fine to cloudy.
15	29·853	68·5	56·7	W.	10·0	0·569	Generally cloudy.
16	29·588	61·0	55·3	W.S.W.	10·0	0·120	Raining.
17	29·832	65·8	55·6	W.	7·0	...	Very fine.
18	29·896	66·7	58·4	W.	7·3	...	Cloudy intervals.
19	30·045	64·5	52·3	W.	8·8	...	Fair generally.
20	29·959	66·0	50·6	W.S.W.	9·0	0·152	Fine to cloudy.
21	29·565	66·0	57·5	W.	10·0	0·040	Raining to 9 A.M.
22	29·449	67·5	56·0	S.W.	10·0	0·121	Frequent showers.
23	29·384	67·1	50·0	W.S.W.	4·8	0·032	Fine to thunder showers.
24	29·344	59·4	49·1	W.S.W.	9·5	0·076	Frequent slight showers.
25	29·162	65·0	53·2	S.S.W.	8·8	0·210	Frequent rains.
26	29·346	61·3	52·4	W.S.W.	7·5	0·002	Fine, squally.
27	29·635	61·9	51·3	S.S.W.	7·3	0·305	Fine early, rain noon to 9 P.M.
28	29·699	63·3	52·8	W.N.W.	3·5	0·084	Fine.
29	29·609	64·0	52·6	W.	10·0	0·474	Frequent rain, heavy from 4 P.M.
30	29·587	64·0	55·0	W.	9·5	1·124	Fair intervals.
31	29·618	62·9	56·7	Var.	10·0	0·301	Heavy rain.
Means .	29·673	64·65	53·69	...	8·22	Total, 4·964	

By kind permisson of the Committee and Principal J. H. Reynolds, M.Sc., Municipal Sch. of Tech., Manchester.

CHAPTER II

DIVISION OF THE RAINFALL—SOURCES OF SUPPLY—CHARACTERISTICS OF WATER OBTAINED FROM VARIOUS SOURCES

OF the rain-water that falls on the earth's surface, one part is absorbed by vegetation, a second part is evaporated, a third part percolates into the earth, and a fourth part passes over the surface of the ground, and, accumulating, forms streams, rivers, and lakes; a large portion of it ultimately reaches the sea.

The latter two parts are made use of for the purpose of water supplies to communities and manufactories.

The portion that percolates into the earth where the strata are porous, is rendered available by sinking shafts to requisite depths and employing mechanical appliances for raising the water to desired heights.

The part of the rainfall that passes over the surface is obtained for water-supply purposes from streams, rivers, natural lakes, and artificial lakes or reservoirs. This portion is the most important part of the rainfall, serving as it does the needs of most of the cities and large towns as well as a large number of smaller communities in this country.

The characteristics of the water obtained from various sources differ, owing to local conditions. Pure water is an unknown quantity in nature, and in connection with domestic water supply the term "pure" is used only in a relative sense, expressing that a certain water does not possess ingredients that are deleterious to health. Absolutely pure water is obtainable by a process of careful distillation as carried out in chemical laboratories, but owing to the great solvent property possessed by water, it cannot long be maintained in such a pure state. When exposed to the air, freshly distilled water will

gradually dissolve quantities of gases, chiefly CO_2 (carbon dioxide), oxygen, and nitrogen, and thus become impure. Pure water is a chemical compound composed of 2 volumes of of hydrogen to 1 volume of oxygen. It possesses the power of dissolving to some extent most of the solid substances with which it comes in contact.

Rain-water is the purest kind of natural water, but it possesses impurities which have been taken up during the passage of the water through the air. The nature of the impurities is largely influenced by the character and amount of gaseous and suspended matter present in the air. In country districts the air is comparatively free from fine particles of solid matter, and the CO_2 present rarely exceeds ·030 per cent. Therefore the impurity taken up by the rain in country districts before it reaches the earth will consist chiefly of CO_2, along with minute solids, probably of volcanic origin.

In the case of towns and cities, large quantities of smoke, soot, and gaseous products are discharged daily into the air from the chimneys of private dwellings, mills, and exhaust shafts in connection with certain manufacturing processes. The rain during its passage to the earth dissolves the ammoniacal, sulphurous, and nitric compounds that are usually present in the air of towns, in addition to CO_2, oxygen, and nitrogen. A comparatively large quantity of finely divided solid matter, chiefly soot, is also carried down, thus further polluting the rain-water. Such water is usually well aerated, owing to the presence of dissolved gases; it gives a faintly acid reaction, and is somewhat discoloured by the fine particles of matter which are in suspension. It is unfit for drinking purposes, but is in some instances used in certain manufacturing processes.

Isolated houses in country districts are frequently supplied with water for drinking and potable purposes from the rain that falls on the roofs of the buildings. The rain-water is, for all practical purposes, pure when it reaches the roof surface, but it immediately takes up, in suspension and solution, quantities of the impurities that usually abound on roofs, and if the gutters be lined with lead, there is some risk of small portions of lead being dissolved and carried in the water.

Generally, rain-water will act upon and dissolve iron, lead,

and zinc, owing to the presence in the water of dissolved gases and the absence of the salts of calcium and magnesium. (The latter substances deposit on the surface of the metals an insoluble thin film which prevents contact between the water and the metal.) It is comparatively free from suspended matter (except in towns, etc.), and is fairly palatable. It is "soft" to soap, and readily forms a lather.

The characteristics of the rain-water that percolates into the earth are affected by the nature and composition of surface material and the earth or rock through which it passes.

The water-yield from underground sources may be classified according to the relative positions of the strata in which it is found. Thus, "surface water" or subsoil water is that portion of the rainfall which is retained in the first pervious layer of earth by an impervious stratum situated immediately beneath the pervious layer. "Deep-seated" water is that portion of the rainfall which falls on an "outcrop" of strata or passes from the surface layer through "faults" and fissures in the first impervious layer and percolates into or through the underlying pervious stratum.

Fig. 3, which shows a section through an outcrop, illustrates the difference between "surface water" and "deep-seated"

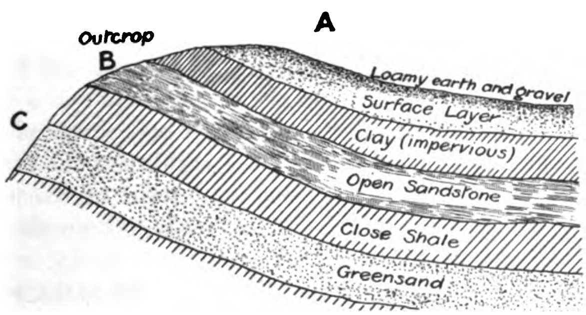

FIG. 3.—Stratification, showing Outcrop.

water. The rainfall on A will accumulate in the first layer of earth and form surface water. The rain falling on the outcrops of the pervious strata B and C will percolate into these strata and pass to a considerable depth below ground. If there be faults or fissures in the clay stratum, the surface water will pass into the open sandstone stratum.

From Fig. 3 it will be observed that the strata A, B, and C vary in composition, therefore the water that accumulates therein will be affected in each case by the character and solvency of the substances forming the strata, and incidentally by the character of the surface of the ground.

Generally, surface water or subsoil water is well aerated and palatable, but is liable to pollution by organic matters in suspension and solution owing to the presence of manure pits, cesspools, sewers, and drains in the stratum. Also, in agricultural districts, the manuring of the surface of the land is a contributory cause of organic pollution of surface water.

Burial-grounds are occasionally responsible for pollution of surface water. A case of pollution occurred recently of the

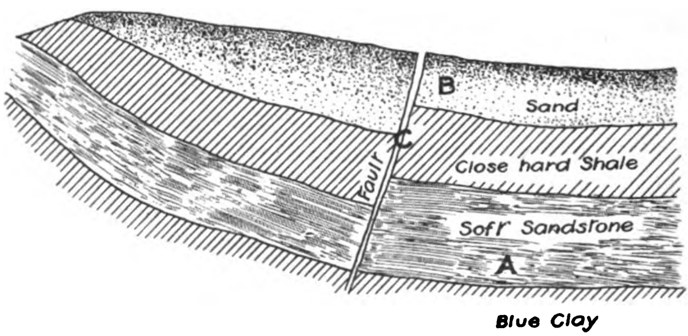

FIG. 4.—Stratification, showing Fault.

water derived from a well which was the sole source of supply to a village; the well was constructed within twenty yards of a burial-ground, and examination of the interior of the well and of the water proved conclusively that soakage from the burial-ground was passing into the well.

If the surface layer contains limestone, the water will take up a quantity of this substance in the bicarbonate form, owing to the presence of CO_2 in the rain-water. This produces "hardness."

Deep-seated water is generally free from suspended matters and organic impurities, owing to the filtering action which occurs during the passage of the water through the materials of which the lower strata are composed. If the strata be composed of limestone or chalk, or if there be a considerable

quantity of these substances present, the water will dissolve the salts of calcium and magnesium in quantities varying with local conditions. The salts of iron, and less frequently the salts of lead, are taken up in a similar manner.

If there be faults or fissures in the impervious strata overlying the pervious strata, the deep-seated water may partake in part of the character of the superimposed surface water. Fig. 4 shows how the character of "deep-seated" water in stratum A may be influenced by the surface water from stratum B passing through the fault C.

Upland Surface Water is that portion of the rainfall which does not pass into the earth, but flows over the surface and forms streams, rivers, and lakes; it is also accumulated in artificial lakes or reservoirs to provide supplies to cities and towns.

The characteristics of this portion of the rainfall differ considerably in the various districts throughout the country, and are influenced principally by the nature of ground over which the water flows. If the surface layer be composed of limestone or chalk, the water will dissolve quantities of the sulphates and carbonates of lime and magnesia. If the ground be covered with decaying vegetation, as obtains in the case of moorland or peaty surfaces, the water will probably be contaminated by organic matters in suspension and solution. The suspended substances may consist of living and dead organisms, chiefly of a non-pathogenic or harmless type, unless the surface be manured with human excreta or farmyard manure, or the drainage from one or more houses on the watershed is permitted to pass over the land and eventually drain into a natural watercourse. Under such conditions the water may contain living pathogenic germs or bacteria that are responsible for such diseases as typhoid, cholera, dysentery, etc. Great care and constant vigilance is necessary to prevent pollution of upland surface water.

The dissolved impurities consist chiefly of small quantities of organic acids such as humic and ulmic acids, that are generated by the action of bacteria on decayed vegetation. Although this class of impurity when present in small quantities has no direct deleterious effect upon the human system, it may be responsible for subsequent pollution during

the passage of the water through pipes of lead, iron, or copper, owing to the solvent action which water containing traces of these acids has upon such metals.

If iron be present in the rocks over which the water flows, the water will be discoloured by the precipitation of the dissolved iron.

CHAPTER III

IMPURITIES OF POTABLE WATER, AND THE METHODS ADOPTED FOR REMOVING SAME

THE impurities of water consist of two classes:—

(1) Suspended matters;
(2) Dissolved matters.

Suspended matters may be of organic and also of inorganic origin.

Organic suspended matters are of two principal types: (*a*) living vegetable and animal substances; (*b*) dead vegetable and animal matters.

The living vegetable substances belong to the following groups:—Fungi of various types, including bacteria; diatoms, algæ, including desmids.

The living animal substances include the various minute forms of insect life, amœba, polyzoa, etc.

The dead vegetable matter includes humus, plant and cell tissue, fibres of wood, and starch grains, etc.

The dead animal matter includes fleshy tissue and fibres, fæces, dead animalculæ and insects, etc.

In addition to the above there are also colloidal matters, which consist of substances that are in a very fine state of division and are diffused throughout the mass of water. They may be removed completely only by the aid of the finest of filters or screens. Colloidal matters, although in such a fine state of division, will not pass through animal membranes by osmosis as dissolved matters will.

The inorganic matters in suspension are chiefly sand, fine particles of clay, carbonate of lime and magnesia, and the insoluble salts of lead and iron.

Dissolved Impurities may be either organic or inorganic in character, in addition to the various gases that are dissolved in natural waters. The former is represented chiefly by urea and its products (*i.e.* ammoniacal compounds), soluble colouring matters, alkaloidal bodies, *i.e.* poisons that are the result of putrefactive changes; vegetable acids, such as humic and ulmic acids.

The dissolved inorganic substances consist principally of mineral salts, such as the chlorides, carbonates, and sulphates of calcium, magnesium, sodium, iron, silicon, and potassium; and less frequently the salts of copper, lead, and zinc.

Dissolved gases are present in variable quantities in all natural waters. They consist chiefly of oxygen, nitrogen, and carbon dioxide. Occasionally waters may contain sulphuretted hydrogen and sulphur dioxide, but such waters would be classed as "medicinal" if these gases are present in comparatively large quantities.

Although all natural waters contain impurities, it is not to be concluded that they are invariably unfit for human consumption. Many of the impurities are of a harmless character, whilst others render the water unsafe for domestic use.

Deleterious Impurities.—Suspended organic matters, which may consist of certain low forms of plant and animal life including specific organisms, are a source of danger in domestic water supplies.

Diseases of the blood and of the digestive organs, such as cholera, dysentery, typhoid, and diarrhœa, are liable to be caused by such impurities.

Suspended inorganic impurities, such as the insoluble salts of lead, copper, and zinc, may cause a disturbance of function in the human system, but such occurrences are rare, as most inorganic suspended matters are precipitated if the water remains quiescent for a short period.

The dissolved impurities that are deleterious may also be of organic and inorganic origin. The dissolved organic matters are rarely directly harmful, except in the case of alkaloids and comparatively large quantities of urea and its allied compounds, but they may be responsible for future contamination, as instanced when acid water comes in contact with pipes of lead, iron, copper, and zinc.

Certain dissolved inorganic substances, as the soluble salts of lead, copper, and zinc (especially lead), are dangerous even when present in comparatively small quantities.

Owing to the extensive use of pipes of lead for the conveyance of water from water-mains to the houses and other buildings, cases of lead poisoning or "plumbism," are much more frequent than is supposed. All people are not similarly affected by the use of plumbic contaminated water. Certain water-borne compounds of lead will accumulate in the systems of some persons and eventually produce symptoms of lead poisoning, whilst other persons who partake of the same water will be unaffected.

Owing to the insidious character of this ailment, many people suffer from mild attacks and occasionally from severe attacks of plumbism, and attribute the cause to other sources. Various palliative measures, including laxatives of a homely character are tried, but without success, the ailment growing in severity meanwhile, until a medical man is called in and proper measures are taken for eliminating the lead from the system. It is stated by medical men that one-tenth of a grain of lead per gallon of drinking-water is sufficient to set up lead-poisoning in some human systems. Therefore, water containing the slightest trace of lead should not be used for domestic purposes.

The following are some of the symptoms suggesting plumbism in the human system:—Constipation, pallor, griping pains in the abdominal region, a blue line along the edges of the gums, loss of appetite, anæmia, and in severe cases a partial dislocation of the bones of the wrist and paralysis of the hands and arms.

The sulphates and bicarbonates of lime and magnesia, when present in quantities not exceeding 10 grains per gallon, are not harmful, though they are responsible for rendering the water "hard" to soap. Larger quantities, however, frequently cause disturbance of the digestive functions of people whose digestive organs are somewhat weak; moreover, vegetables cooked by the aid of hard water are not easy to digest. On the other hand, such water will not attack and dissolve lead, zinc, or copper.

Physical Tests applied to water may be useful as

a preliminary to a more searching test. They may be classed as:—

(1) Colour.
(2) Odour.
(3) Taste.
(4) Transparency and brightness.

Colour.—This is influenced by the matters in solution principally, but may also be due to colloidal colouring substances. A good water should have preferably a bluish tinge when viewed through a depth of not more than 2 ft. A brown tint usually indicates peaty contamination, whilst a reddish tint may be due to the presence of iron.

Odour may be observed by tests with either cold or warm water (*i.e.* at 100° F.). Pure water, when warm or cold, has neither a disagreeable nor a clearly perceptible odour, but water polluted with organic matters such as urine and fæces, when warmed and shaken violently in a glass-stoppered bottle, will evolve characteristic odours of ammonia and vegetable matters in a decaying condition.

Taste will frequently give a fair indication of impurities such as iron, magnesium, and sodium compounds; whilst the disagreeable flavour imparted to water by fungi, algæ, etc., may occasionally be detected.

Transparency and Brightness.—The presence of fine particles in suspension materially affect the transparency and in a lesser degree the brightness of water. Brightness and sparkling qualities are imparted to water by dissolved gases. These characteristics are frequently misleading. The gases may originate from the soakage from cesspools, manure heaps, leaky drains, and sewers, etc. Thus, whilst the water may have a clear, sparkling appearance, it may be contaminated by specific organisms responsible for water-borne diseases. Such water, when obtained from wells and other underground sources, should be looked upon with suspicion.

Biological Examination of drinking-water is essential to prove the presence or absence of harmful micro-organisms. Microscopical examination of the raw water and of cultures grown on suitable media is necessary for this purpose. During recent years the importance of the biological exami-

nation of water has been advocated by all the leading experts. The chemical examination will give some indication of the previous history of the water, but will not determine its freedom or otherwise from pathogenic organisms, *i.e.* organisms that are responsible for certain diseases.

Chemical Examination of water, or water analysis, is undertaken to ascertain the nature of the impurities of water. The results obtained from careful analyses afford reliable indication of the nature of any chemical impurities that may be present.

Metallic Impurities in water consist chiefly of the salts of "lead, copper, zinc, and iron." The first three are deleterious to health, lead having a more injurious effect than the others. Iron is objectionable principally on account of the discoloration of fabrics, etc.

The presence of these metals in water can be detected by applying the following tests:—

Lead—

1. If sulphuretted hydrogen be passed through the water, a black coloration of plumbic sulphide will be observed.

2. If potassium chromate be added, a yellow coloration, due to lead chromate, is obtained.

Copper—

1. Contact with sulphuretted hydrogen produces a brownish black coloration, due to formation of copper sulphide.

2. Titanous sulphate in the presence of sulphuric acid will detect mere traces of copper in water. A very fine reddish precipitate of metallic copper is obtained.

Iron—

1. The addition of potassium sulphocyanide will give a blood-red coloration, due to ferric sulphocyanide.

2. Tannic acid gives an inky coloration of tannate of iron.

Zinc—

1. Sulphuretted hydrogen in the presence of ammonia gives a white coloration of zinc sulphide.

2. If zinc be suspected in a sample of water, evaporate a large quantity to dryness; heat the residue on charcoal, moisten with a little cobalt nitrate solution, and again heat. If zinc be present, a green coloration will be observed.

The Methods adopted for the Purification of Water are as follows:—

(1) Precipitation.
(2) Screening.
(3) Filtration.
(4) Aeration.
(5) Ozonisation.

Precipitation is adopted in the case of water that contains a considerable quantity of suspended matter. River-water and stream-water, and in some cases rain-water, are much improved if allowed to remain quiescent for from six to forty-eight hours.

The grosser particles of organic and inorganic solid matter are thereby precipitated, and the flocculent substances rise to the surface. The water is drawn off, generally from the top, by means of a floating arm, which adjusts itself automatically with the fall of the water-level.

Precipitants such as alum and iron oxide are used, which also act as coagulants, and bring down a considerable percentage of the finer suspended matters that are not precipitated when the water is merely allowed to remain quiescent. A mixture of chloride of iron and bleaching powder, *i.e.* chloride of lime, has been tried, but the free chlorine which is produced is difficult to get rid of, owing to its solubility.

Precipitation is indispensable for turbid water, whether the water be required for drinking purposes or for manufacturing processes.

Screening consists of passing the water through fine sieves or screens, usually of copper wire, having 2500 to 5000 apertures per square inch. This process is adopted in some cases at a point where the water leaves the reservoir. Gross particles of organic and inorganic matters, and comparatively large vegetable and animal organisms, are thereby arrested and prevented from passing into the water-mains.

The efficiency of the process depends upon the fineness of the screens. It is useless for removing micro-organisms from water.

Filtration consists in passing the water through a filtering medium composed of a substance the particles of which are

not so closely compacted as to prevent the water from percolating between them.

Matters in Solution cannot be removed by Filtration, but all suspended matters may be removed if the filter be sufficiently fine to prevent the passage of solids through its interstices.

Filtration may be considered under two headings:—

(1) Waterworks filtration;
(2) Domestic filtration.

The former is undertaken by the waterworks authorities previous to the distribution of the water through the mains to the consumers.

Filtration on a large scale may be either of the "low-pressure" or "slow" type, or of the "high-pressure" type. The former consists of passing the water through composite beds of sand and gravel of various grades. The head of water which forces the water through the filtering media rarely exceeds 2 ft. 6 ins., and is oftener less than 1 ft.

The rate of flow of the water through this type of filter is comparatively slow, on account of the small head of water under which the filter works. The relative depths of sand and gravel are varied for different waters. Fig. 5 shows a section through a portion of a large sand-filter. It will be observed that the base of the filter-bed is formed of concrete on which a system of underdrains, formed of special channels or bricks, is constructed; immediately over these drains a layer of boulders of from 2 to 4 ins. cube are placed, followed by two layers of gravel of different sizes, the fine gravel being uppermost. Finally, a layer of river sand of from 1 ft. 6 ins. to 3 ft. 6 ins. in thickness is placed on the gravel.

The water is admitted to the top of the filter by means of special conduits that are arranged so as to minimise the disturbance of the surface layer of the sand. In some instances the stand-pipe outlet is constructed so as to allow of adjustment of the head of water under which the filter works. By this means the rate of flow through the filter may be regulated in accordance with the condition of the filter-bed.

When a low-pressure sand-filter or "slow" sand-filter is started to work, the water passes through practically unaltered;

very little of the suspended matter is intercepted excepting some of the grosser particles. With a continuation of the working of the filter a gradual improvement of the filtrate takes place. The time required for the bed to attain a reasonable degree of efficiency depends upon the rate of flow, the condition of the raw water, and the temperature of the water and the air. The desired condition is more quickly obtained in summer than in winter.

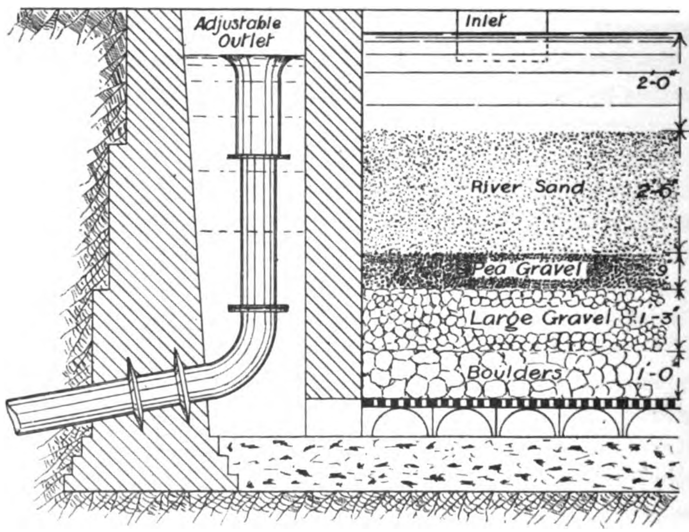

FIG. 5.—Section through Sand-Filter.

The gradual increase of the efficiency is due to the formation of a felt-like structure in the surface layer of sand, consisting of vegetable growths, such as algæ and desmids, etc., which tend to reduce the sizes of the interstices or channels through which the water passes. Silt is also deposited on or just below the surface of the sand, thus causing a further increase in efficiency. Eventually the felt-like growth of vegetable filaments is of sufficient compactness and area to arrest minute forms of animal and vegetable life.

The importance of preserving this "filtering skin" is generally recognised. On the slimy surfaces of the interlacing filaments bacteria are entangled, and either oxidised or destroyed by algæ and other agents.

Colloidal matters are also arrested on the slimy surfaces of the filtering skin, and are disintegrated and finally oxidised.

When working under proper conditions, well-designed, slow sand-filters will remove most suspended matters, including bacteria.

Cleaning of Filters.—The density of the filtering skin, which extends only 2 to 3 ins. below the surface, gradually increases until the flow of water through the filter is so reduced as to necessitate the removal of a portion of the upper layer of sand.

Usually ½ in. of sand is carefully scraped off the upper surface, and is washed and again used during the reconstruction of the filter-bed.

On resumption of the use of the filter, the water is allowed to pass to the waste channel for a period of from one to two days, until the filtering skin offers a reasonable degree of resistance to the water flow.

During recent years the high-pressure type of filter has been used to a large extent both in England and on the Continent. There are many makers of these filters, each developing certain features advantageous or otherwise. Generally they are arranged to work under a pressure of from 5 lbs. to over 100 lbs. per sq. in., and are cylindrical in shape and formed of wrought iron or mild steel. The filtering medium usually consists of crushed quartz or silica grit arranged in one or more beds. Oxidising substances, such as oxidium, which is formed of iron oxide, silica, etc., as used in the Candy filter, are placed between two layers of quartz, and exert an oxidising influence upon organic matters.

The rate of flow per unit area through these filters is many times greater than the flow through "slow" sand-filters, but the makers claim that their efficiency is in no way impaired thereby, if ordinary precautions be taken in their management.

Fig. 6 shows a section through a high-pressure filter. The raw water enters at the top, and the filtered water passes though the conduit attached to the base. A scour-pipe is provided having its outlet immediately above the upper surface of the filtering medium.

The compartment in the top of the cylinder is charged with air under pressure, which will be absorbed by the water

and carried through the filter, thereby assisting in the oxidation of the organic matter.

Owing to the rapid rate of filtration, the filter requires scouring at least once per day. This is accomplished by opening the valves A and B, and closing valve C, thus reversing the flow. The surface layers or skins are agitated, and the silt, etc., is removed through the scour-pipe.

In certain types, horizontal revolving arms are provided by

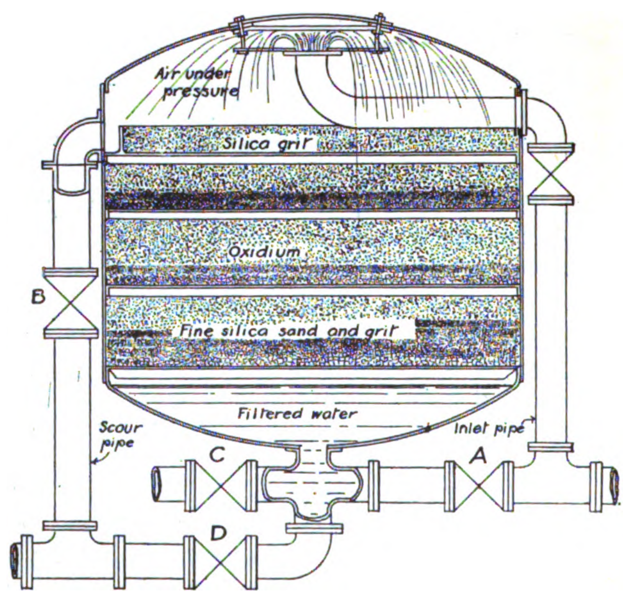

FIG. 6.—High-pressure Filter of the Candy type.

which the filtering media are agitated during scouring operations. The arms may be solid, or may consist of perforated tubes through which water is discharged, thus facilitating the cleansing process.

The intervening layer of oxidium (shown in Fig. 6) absorbs oxygen each time the filter is emptied, and supplies the stored oxygen to the water during filtration.

After cleansing, the water is allowed to pass to waste through the pipe D for several minutes, in order to compact the filtering media.

The makers of high-pressure filters claim that practically all the bacteria present in the raw water are retained on the filtering media, also that most of the organic matter is eliminated.

The advocates of slow sand-filters consider that the rate of filtration in the high-pressure type is too rapid to achieve good results.

The first cost of slow sand-filters, including the necessarily large area of land for the same, is considerably greater than that of high-pressure filters of equal capacity. The maintenance charges of the latter are also less than those of the former.

Domestic Filtration is of two types:—

(1) Low-pressure filtration;
(2) High-pressure filtration.

Low pressure filtration includes the use of small portable filters and also small filtration plant for country houses that are supplied by rain-water collected from roofs and other impervious surfaces, or water taken from streams in the vicinity of the house.

High-pressure domestic filtration generally consists in attaching a filter to the water service pipe from the street main, or to the supply pipe from a storage cistern.

Portable low-pressure filters consist of vessels containing filtering media through which the water percolates from the higher to the lower portion, a tap being arranged to draw off the filtered water; also, one or more filter tubes may be carried in a small box for outdoor use.

The filtering media generally used are:—

(1) Vegetable charcoal (charred wood);
(2) Animal charcoal (calcined bones);
(3) Spongy iron;
(4) Fossil earth;
(5) Baked clay of the porcelain type;
(6) Close-grained sandstone.

Fig. 7 shows a type of portable charcoal filter, consisting of two vessels. The inner vessel A contains the filtering medium B, which may consist of either vegetable or animal charcoal, or

of spongy iron; the filtered water percolates through B into the reservoir C, from whence it may be drawn by opening the tap D.

A block of close-grained sandstone may be inserted as a filtering medium instead of the charcoal.

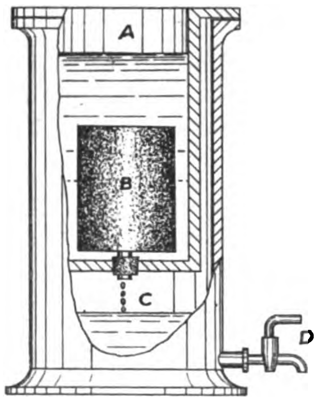

FIG. 7.—Charcoal Filter.

The rate of percolation of the water through the filtering media in low-pressure types is comparatively slow.

Efficiency of Filtering Media.—During recent years a considerable amount of research work has been carried out by eminent scientists in connection with the efficiency of filtering media. The results obtained and verified by different authorities should have the effect of eliminating the use of filters which are not reliable.

The function of a domestic filter is to render the water which passes through it absolutely sterile.

A considerable amount of ignorance prevails in respect to the efficiency of various filters, but experiments by Pasteur, Frankland, Chamberland, Plagge, and others have proved beyond doubt that filters that depend upon charcoal, spongy iron, sandstone, and similar materials, will not remove all micro-organisms from water.

Vegetable Charcoal possesses the property of removing odours from water. Water contaminated by lead when passing through a *new* vegetable charcoal filter will have the lead removed for a time, but the plumbic retentive properties of the filter are soon exhausted, and the lead eventually passes through with the water.

Animal Charcoal, which is prepared by charring bones, is a strong decoloriser. Water that is discoloured will be rendered limpid, sparkling, and bright by passing through a block of animal charcoal.

Spongy Iron has a slight oxidising effect upon the organic impurities in water, but it will not arrest micro-organisms.

Sandstone simply acts as a screen, of insufficient value to completely sterilise water.

In connection with filters using the foregoing media, sponges are frequently used to arrest the grosser particles, but they are a source of danger, as they swarm with bacteria and provide a suitable propagating ground for the multiplication of the germs.

Experiments have proved conclusively that the arrested organisms eventually grow through this filtering media, and are liable to produce a greater degree of pollution in the filtrate than obtains with the raw water.

Germ-proof filters are confined to those using a medium of either fossil earth or baked clay of the porcelain type.

The Berkefeld Filter, shown in Fig. 8, is of the form using fossil or diatomaceous earth known as kieselguhr, as the

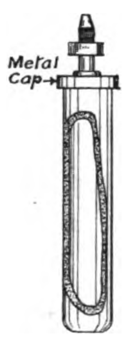

Fig. 8.—Berkefeld Filter Tube.

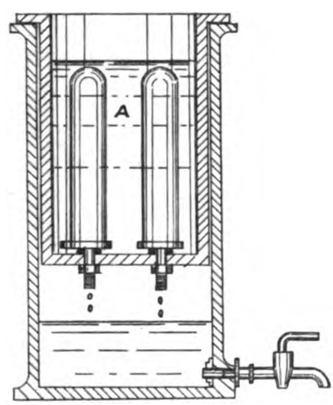

Fig. 9.—Berkefeld Filter Tubes in Battery.

filtering medium. The fossil earth is formed into candles, the ends of which are fitted with metal caps possessing tubes of about $\frac{3}{8}$ in. diameter, through which the filtered water passes. The filtration may be arranged for on the non-pressure or open system, or on the pressure or enclosed principle.

For non-pressure filtration one or more filter-tubes are fixed in the top part of a vessel (A, Fig. 9), which receives the raw water. The tubes are detachable for cleansing purposes.

The rate of filtration of this type of apparatus is slow, but

it is also continuous if periodic attention be given to the condition of the filter candles.

The pressure type consists of one or more filter-tubes, enclosed by a vessel of cast-iron, gunmetal, copper, or brass.

The daily yield required of a filter under a given pressure decides the number of filter-tubes to be used. For household purposes where drinking-water only is to be filtered, the apparatus shown in Fig. 10 may be used. It consists of a filter-tube of baked fossil earth enclosed in a metal casing of brass or iron. The water is admitted to the metal cylinder

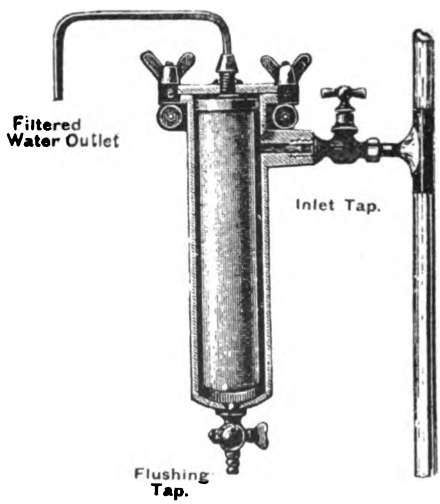

Fig. 10.—Berkefeld Filter Tube attached to Tap.

through the tap connection to the service pipe, and percolates inwards through the tube. The filtrate passes through the vertical pipe attached to the filter-tube.

If a large supply of filtered water is necessary, one or more batteries of tubes may be engaged in the work, each battery being independent but communicating with a common conduit, and so controlled and arranged as to facilitate cleansing without necessitating the total suspension of filtering operations of the whole of the system. This arrangement is preferable to the use of one large battery, which would result in frequent total stoppage when renewal or cleansing of the filter-tubes became necessary.

The Pasteur-Chamberland Filter is formed of a special kind of clay resembling porcelain when fired. It is a white, hard substance, close-grained, yet sufficiently porous to permit of slow percolation of water through the interstices. It is moulded into tubes having walls of about $\frac{1}{8}$ in. thickness, and glazed nozzles at the outlets. Fig. 11 shows a filter-tube of the Pasteur-Chamberland type. Great care is essential in the manufacturing process, and the makers carefully test the tubes before submitting them for sale.

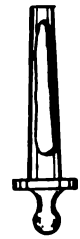

Fig. 11.—Pasteur Filter Candle.

For procuring a household supply of drinking-water, a single filter-tube or candle enclosed in a nickel-plated brass cylinder is attached to a tap of special design, which in turn is connected with the water service pipe, as shown in Fig. 12. This filter, under a pressure of 20 lbs. per sq. in., will pass about 5 gallons of water per day.

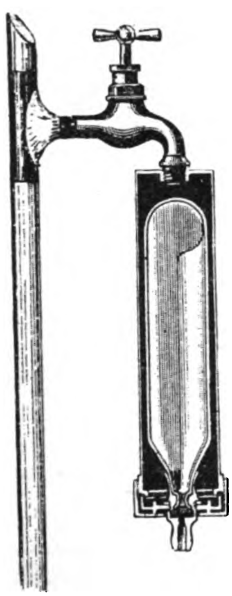

Fig. 12.—Pasteur Filter attached to Tap.

The apparatus shown in Fig. 13 is a type of pocket Pasteur filter. It consists

Fig. 13.—Pasteur Filter, Battery of Non-pressure Type.

of a battery of three filter tubes attached to a metallic tube, to which a pump is connected. The tubes are placed in the spring, stream, or river-water, and the pump is operated. The water thus obtained is absolutely safe for drinking purposes.

The efficiency of the Pasteur filter has been proved by a number of authorities after extensive microscopical and

biological examinations of the filtrates obtained at different periods during the trials. Water that has passed through a Pasteur filter is rendered sterile by the retention of all micro-organisms on the surface of the filter-tube. The efficiency is maintained even after the filter has been in use for a considerable period without the filter-tube having been cleaned; but eventually the deposit is sufficient to entirely close the pores of the filter, thus preventing the passage of water through the same.

Although the extreme fineness of the pores or passages between the particles of the filter has a considerable bearing on the success of its sterilising influence, it is said by experts that its microbe-retention powers are also due in some measure to molecular attraction between the micro-organisms and the molecules of the filtering media. This will account for the retention of organisms in the Pasteur filter, the interstices in which are much larger than the living and dead particles which are arrested even when under the propelling influence of a comparatively high pressure of water.

The periodic cleansing of the Pasteur filter-tube is essential to remove the gelatinous deposit and to destroy the organisms and spores that are retained on the filter. This is best accomplished by first brushing and then boiling the filter-tubes in slightly acidulated water for half an hour.

The Berkefeld filter allows of a more rapid passage of the water than does the Pasteur, but the results of numerous experiments show that its efficiency is proportionately less than that of the slower Pasteur filter. The filtrate is said not to be sterile either immediately after the tube is first used or subsequently; also, if not attended to periodically, there is some risk of the micro-organisms that are arrested on the surface "growing" through the filtering media, and thus contaminating the filtrate.

The "Doulton" porcelain filter is similar in principle and design to the "Pasteur-Chamberland" filter. It is formed of selected porcelain clays carefully ground and burnt. Biological tests of this filter have been made by several experts, and satisfactory results obtained.

It may here be stated that the function of a domestic filter consists in the prevention of the passage through the filter of

micro-organisms or their spores which may be present in the water to be filtered. A filter which will not accomplish this cannot be relied upon with absolute safety.

The candle of the Berkefeld filter is very fragile, and during cleansing the thickness of its walls is gradually reduced. It is considered by some authorities that these filters should be brushed and well boiled daily.

Certain experts contend that all water intended for drinking should be filtered on the premises.

Filtration on a large scale previous to distribution to the consumers will probably remove or at least reduce the number of the micro-organisms present in the raw water, but there always exists the probability of subsequent pollution during distribution, and in some instances during storage on the premises, which can be removed only by a system of domestic filtration.

The purification of water by Ozone has been adopted during recent years on the Continent, and is now being adopted in certain localities in England. Ozone is an allotropic form of oxygen which possesses great oxidising powers. It has the effect of rendering sterile, water that contains micro-organisms.

Ozone for water purification is prepared by the silent discharge of high voltage electric current through absolutely dry air. The current pressure used in the ozonisers is frequently as high as 80,000 volts. The air passing through the apparatus is dried by contact with calcium chloride or other hygroscopic agent, or it is passed through a refrigerator, where the water-vapour is deposited as frost or snow.

Care is necessary during the preparation of the ozone to prevent the formation of oxides of nitrogen, which are liable to be produced if "sparking" occurs at the electrodes. These gases act injuriously on water.

In several instances the water obtained on the Continent from rivers that are notably impure is rendered practically sterile by this method and supplied to consumers for drinking and potable purposes.

If a comparatively large quantity of organic matter be present in a water to be treated, it may be necessary to subject it to a preliminary filtration on a coarse filter to remove the major portion of the organic matter, otherwise the ozone would

attack and oxidise this, thereby necessitating the use of an abnormal quantity of ozone per unit volume of water to effect thorough sterilisation.

Several forms of apparatus are in use for the treatment of water by ozonised air. Fig. 14 shows a part section through an ozonising plant. A large cylindrical chamber of either cast or wrought iron is provided with perforated trays that contain beds of washed gravel. The water, which has been subjected to a preliminary screening process where necessary, is admitted at the top of the cylinder A, and is discharged through rows of perforated pipes or other apparatus that will divide the water into fine streams. The ozonised air is forced into

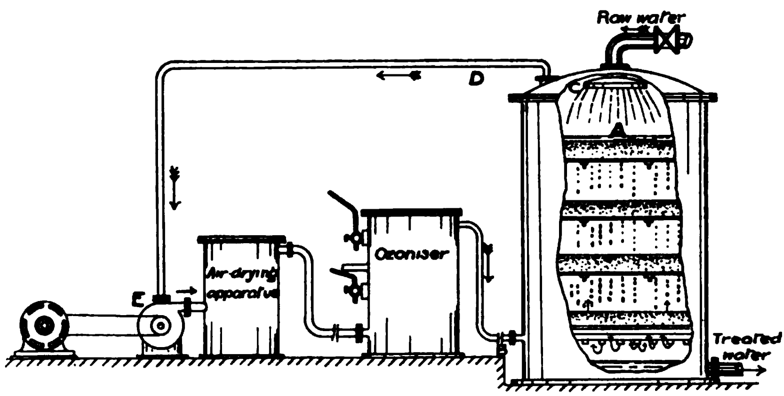

FIG. 14.—Apparatus for Purification of Water by Ozone.

the bottom of the chamber or water-tower A through the pipe B, and escapes from nozzles or perforations. During its passage through the beds of gravel it intimately mixes with the water, which is further broken up, and a maximum area of contact is thus obtained between the ozonised air and the water. A quantity of the former is dissolved and rapidly attacks and oxidises organic matters, including micro-organisms.

The spent air accumulates in C and is withdrawn through pipe D by the high-speed air-propeller E, which forces it through the drying and ozonising apparatus and again into A. By this device the unused ozone which would escape if a continuous supply of fresh air were delivered to the ozonisers is utilised.

The water that has passed through the purification process is exposed to the air for a short time to eliminate any traces of ozone which it may contain; afterwards it can be supplied to the consumers.

The degree of concentration of ozone, *i.e.* the weight per unit volume, is varied with the treatment of different waters, but is generally from 1 gram to 4 grams of ozone per cubic metre of air. The higher the degree of concentration, the greater the cost per unit of ozone.

The cost of water purification by this method is given by some authorities as from 20s. to 45s. per million gallons treated.

Hardness of Water is the term used to indicate that certain classes of water are hard to soap, *i.e.* that a lather is not readily formed with soap. The term is used in a comparative sense, and applies to water that contains more than a stated quantity of earthy salts per unit of volume.

Hardness of water is expressed by "degrees." One degree of hardness is equivalent to 1 gr. of carbonate of lime, or a quantity of other earthy salts which will neutralise the same volume of a standard solution of Castile soap as would be neutralised by 1 gr. of lime in 1 gall. of water.

Waters that contain more than 6 grs. of lime carbonate, or its equivalent per gallon, are classed as hard waters; and waters that contain 6 or less grains of lime carbonate, or its equivalent per gallon, are classed as soft waters.

Hardness may be of two classes:—

(1) Temporary hardness;
(2) Permanent hardness.

Temporary hardness is so called on account of the ease with which it may be eliminated from the water. Such hardness is due to the presence of the carbonates of lime and magnesia (chiefly the former).

These salts are practically insoluble in water that is free from CO_2, but are readily dissolved by water containing CO_2.

Permanent hardness is caused by the presence of the sulphates, nitrates, nitrites, and chlorides of lime, magnesia, and other salts, which are more stable when in solution than are the bicarbonates of lime or magnesia.

Temporary hardness may be removed by—

(1) Boiling the water;
(2) The addition of milk of lime.

In the first case the CO_2 is driven off, and the insoluble carbonate precipitated as follows:—

$$\underset{\text{Temporary hard water.}}{\left.\begin{array}{r} Ca(HCO_3)_2 \\ \text{or}\quad Mg(HCO_3)_2 \end{array}\right\}} = \overset{\text{Temporary hard water, after boiling.}}{\underset{\text{Precipitated.}}{\left\{\begin{array}{l} CaCO_3 \\ MgCO_3 \end{array}\right\}} + \underset{\text{Escapes in gaseous form.}}{CO_2} + \underset{\text{Softened water.}}{H_2O}}$$

The carbonates of lime and magnesia are deposited in the form of a fine powder. In hot-water service installations this deposit gives a considerable amount of trouble, which is referred to in a later section, dealing with hot-water supplies.

The second method, which consists of the addition of milk of lime to the temporary hard water, is known as Clark's process.

The reaction may be stated thus:—

$$\underset{\text{Temporary hard water.}}{Ca(HCO_3)_2} + \underset{\text{Milk of lime.}}{Ca(HO)_2} = \underset{\text{Double precipitate of carbonate of lime.}}{2CaCO_3} + \underset{\text{Softened water.}}{2H_2O}$$

The lime (CaO) has a great affinity for the CO_2, which is holding the carbonate of lime in solution, and immediately combines with it, forming a carbonate of lime which is precipitated along with the original carbonate.

The reaction in the case of the magnesium bicarbonate is similar.

This process can be adopted (on a large scale, or on a small scale) for reducing temporary hardness of domestic water.

The reduction of permanent hardness is not often undertaken in connection with drinking-water supplies.

Permanent hardness is due principally to the presence of sulphates of lime and magnesia.

These salts cannot be reduced by boiling, although the calcium sulphate is precipitated in steam boilers when the temperature of the water exceeds 300° F.

Hardness of water is said to be beneficial when it does not exceed 10°, but the opinions of medical men differ in this respect. Some experts state that the lime salts play an

important part in the calcification of the bones of children, thus tending to prevent the occurrence of rickets (a complaint due to an insufficiency of calcium salts in the bones), whilst it is the opinion of many that the influence of this feature is small, and is entirely overshadowed by the evils due to the digestive disturbances that are caused by the calcium salts in the systems of the weakly constituted. Certainly these salts add to the difficulties of the proper cooking of foods, particularly vegetables, and these require to be boiled for a longer period if hard water be used instead of soft water.

In addition to the foregoing, hard water is objectionable in other ways. It wastes a considerable amount of soap before a suitable lather is obtained, and in laundry work the flocculent scum formed by the combination of the soap and the salts of lime and magnesia permeates the fabrics that are being cleansed, and renders the washing operation one of great difficulty. The inner surfaces of baths, sinks, and lavatories that are supplied with hard water become coated with this scum, which is difficult to remove. In many cases a periodic cleansing of the fittings by the application of a solution of caustic soda is necessary to remove the scum, and to prevent a nuisance arising from its decomposition.

To determine the Hardness of Water, a solution of the best white Castile soap, or of a preparation consisting of a mixture of potassium carbonate and lead plaster (emplastrum plumbic), is used.

The former, which is generally adopted, is prepared by dissolving shredded white Castile soap in a 35 per cent. solution of alcohol. The solution is standardised against a standard hard water, of which 1 c.c. = 1 mg. of $CaCO_3$, by diluting with 35 per cent. alcohol until 1 c.c. of the soap solution will neutralise the lime in 1 c.c. of the standard hard water. In other words, 1 c.c. of soap solution = 1 c.c. of hard water of 1° of hardness.

The total hardness is first determined, and afterwards the permanent hardness. The difference will give the temporary hardness.

To determine the total hardness, 70 c.c. of the water are titrated with a standard soap solution from a burette. The water is contained in a glass-stoppered bottle, which is vigorously

shaken when the soap solution is added, and then allowed to rest. If the "scum or lather" which forms on the surface breaks or cracks within four minutes, a further quantity of soap solution is added, and the bottle-content again agitated. This process is repeated until the "scum" remains intact for four minutes. The quantity of soap solution used is then ascertained, each cubic centimetre of which = 1 gr. of lime per gallon, or 1° of hardness.

If more than 15° of hardness are present, 35 c.c. of the water must be taken and made up to 70 c.c. with distilled water. The test is carried out as described, and the result multiplied by 2.

To determine the permanent hardness, 70 c.c. of the water are reduced to 35 c.c. by boiling, during which process the carbonates of lime and magnesia are precipitated. The residue is filtered and made up to 70 c.c. with distilled water, and titrated with the soap solution. Each cubic centimetre of soap solution = 1° of permanent hardness.

The temporary hardness is obtained by subtracting the permanent hardness from the total hardness.

The reduction of temporary hardness in the case of domestic water supplies is accomplished on a large or small scale by adding milk of lime or calcium hydrate to the water. In hard-water districts where the temporary hardness is excessive, the process can be carried on at a small cost, and the water is thereby greatly improved for potable and dietetic purposes.

The lime-water is added in sufficient quantity to reduce the bicarbonates by uniting with the CO_2, which holds them in solution.

Two methods are adopted for removing the precipitated $CaCO_3$. In the first method the treated water is allowed to remain quiescent in tanks of suitable capacity, and then decanted after a period of from twelve to twenty-four hours. Where large quantities of water are treated this method is not satisfactory, owing to the large storage accommodation required and the difficulties in connection with the removal of the sludge.

The second method consists in screening the treated water. For this purpose the "Porter-Clark" apparatus is used. This consists of iron vessels in which the lime is added to, and thoroughly mixed with the hard water. The precipitate of the carbonates of lime and magnesia is removed by forcing the water through fine canvas screens—an apparatus for treating a

large quantity of water occupies a comparatively small space. The cost of maintenance is less than in the first method, and there is less risk of a portion of the precipitate being redissolved by the CO_2 which the water will absorb when exposed freely to the air for several hours.

The reduction of permanent hardness is rarely attempted in the case of domestic water supplies; but for laundry work, steam-raising, and certain manufacturing processes, it is advisable for economical reasons, if the total hardness be excessive, to reduce it to 3° or 4°.

The reagents used for this purpose are:—caustic soda, NaO, or sodium hydrate, NaOH; sodium carbonate (washing soda), $Na_2CO_3 + 10H_2O$; and lime, CaO.

The quantities to be used vary with the total hardness and the proportion of temporary to permanent hardness.

It is considered inadvisable to attempt the total reduction of the hardness. The most economical results are obtained if the reduction is not carried below 4° of hardness.

Sodium hydrate and lime are added where the temporary hardness exceeds the permanent.

The sodium hydrate acts upon the calcium sulphate to form calcium hydrate and sodium sulphate. The released calcium hydrate precipitates a portion of the calcium bicarbonate, and the remainder of the temporary hardness (if any) is reduced by the addition of lime.

The following equation expresses the reactions which occur simultaneously:—

$$\underset{\substack{\text{Calcium}\\\text{bicarbonate}}}{CaCO_3CO_2} + \underset{\substack{\text{Calcium}\\\text{sulphate}}}{CaSO_4} + \underset{\substack{\text{Sodium}\\\text{hydrate}}}{2NaOH} = \underset{\substack{\text{Calcium}\\\text{carbonate}}}{2CaCO_3} + \underset{\substack{\text{Sodium}\\\text{sulphate}}}{Na_2SO_4}$$

If the permanent hardness exceeds the temporary, carbonate of soda is used instead of sodium hydrate. The use of the latter reagent with such water would result in more calcium hydrate being disengaged than would be required to reduce the temporary hardness.

The reaction with carbonate of soda is expressed by the following:—

$$\underset{\substack{\text{Sodium}\\\text{carbonate}}}{Na_2CO_3} + \underset{\substack{\text{Calcium}\\\text{sulphate}}}{CaSO_4} = \underset{\substack{\text{Calcium}\\\text{carbonate}}}{CaCO_3} + \underset{\substack{\text{Sodium}\\\text{sulphate}}}{Na_2SO_4}$$

This reduces the permanent hardness, after which the temporary hardness is removed by the addition of lime.

The precipitation of the lime and magnesium salts is responsible for the elimination of a large portion of the suspended organic matter. The minute organic particles become entangled with the inorganic salts, and are "brought down."

For steam-raising, the presence of a soluble salt such as sodium sulphate in boiler-feed water is objectionable, as it is one of the causes of "foaming" or "priming," with the attendant evil results.

Under such conditions barium carbonate may be used, but the treated water will require to be carefully filtered, or allowed to remain quiescent until the whole of the insoluble salts are precipitated.

The lime and soda treatment requires special apparatus for mixing and adding the reagents to the water and removing the precipitate.

Fig. 15 shows a section through the "Reisert" automatic water-softener.

The lime is slaked in the compartment A, whence it is delivered to the lime-saturator B. Soda is dissolved in the compartment C, and enters the soda-chamber D through the pipe Q. The hard water is led to the distributing tank E, whence it passes through the micrometer valves 1, 2, and 3 to the soda-chamber, lime-saturator, and mixing-pipe respectively.

Sufficient soda solution for one day's use is admitted to the chamber D through the cock Q. The valve I is adjusted to deliver water at a required speed to displace the soda solution through the dip-pipe and discharge it into the mixing-pipe. The lime-saturator B is likewise supplied through the valve 3 and the pipe O, which passes to the bottom of the conical chamber, thus ensuring a proper mixing of the lime and the water.

The lime-water, hard water, and soda solution enter the pipe E simultaneously, and are intimately mixed before reaching the reaction chamber F. The treated water overflows through the pipe J, and passing through the filter K, enters the clear-water tank L, whence it is delivered through M to a storage tank.

When the quantity of precipitate retained in the filter K

is sufficient to materially reduce the rate of flow to the tank L, the head of water in the chamber F increases until the siphon L comes into operation. The content of F is then siphoned through T. Meanwhile the flow through the filter is reversed, and the water in the tank L automatically removes the pre-

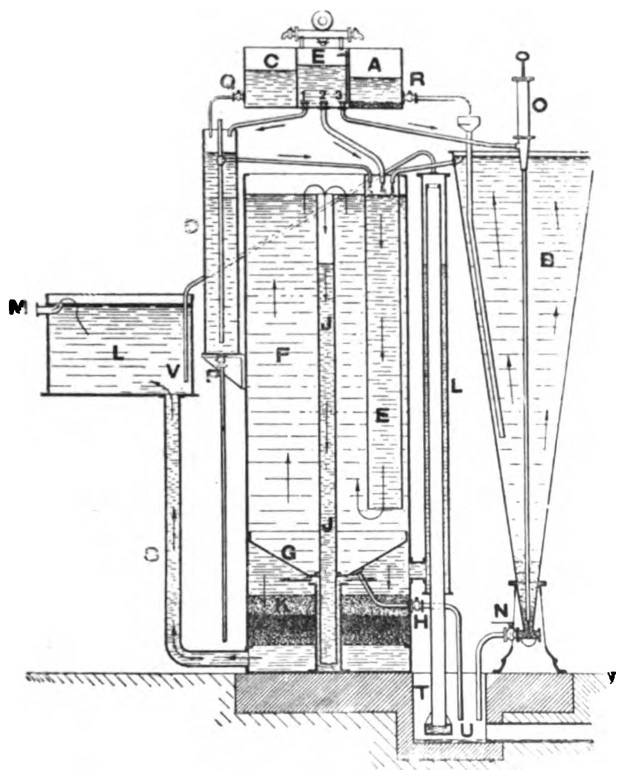

Fig. 15.—"Reisert" Water-softening Apparatus.

cipitate through the siphon to the waste channel U. The small pipe V admits air to the siphon when the tank L is emptied.

The cleansing of the filter is thus carried out automatically.

The micrometer valves 1, 2, and 3 are adjusted according to the quantities of the reagents required.

CHAPTER IV

SPRINGS, WELLS, AND BORE-HOLES—APPARATUS FOR RAISING WATER—RAIN-WATER COLLECTION AND STORAGE

SPRINGS are of two types—main or "deep-seated springs" and "surface springs." Fig. 16 shows a section through several strata. This illustrates the relative positions in which the water is collected. It will be observed that the surface spring is caused by the water that percolates into the surface layer of earth, travelling by gravity towards the lowest point in the stratum, where it issues on the surface of the ground. Such

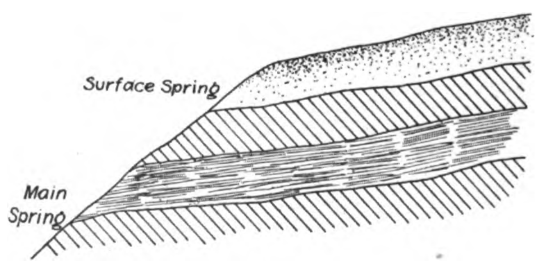

FIG. 16.—Stratification indicating Surface and Main Springs.

water should always be looked upon with suspicion, owing to the probable polluting influence of the subsoil.

The water that supplies the "main spring" arises from a stratum situated beneath the first impervious layer of earth, having fallen in the form of rain on the outcrop of the stratum at a higher level, and percolated through its interstices to the lower level, where it escapes on the surface.

Main springs may also be due to a fault in the first impervious layer of earth, as instanced at A, Fig. 17. If the water is not contaminated by water from the surface layer, it is usually of good quality, and quite suitable for drinking

purposes. On the other hand, if polluted by surface water (as would obtain in the example, Fig. 17), it is unsafe for domestic use.

To render spring-water available for domestic use it is necessary to arrange for the construction of a watertight tank near to the point where the water issues on the surface of the ground. Groups of houses in villages and isolated country districts are in some instances supplied by this method, but great care is necessary to determine the correct source of the supply, and to protect the same from surface pollution.

Isolated country houses may be supplied by water from a deep-seated spring on a hill-side, if the flow be fairly constant and is not materially influenced by a period of drought. A watertight tank, covered in to protect the water from surface

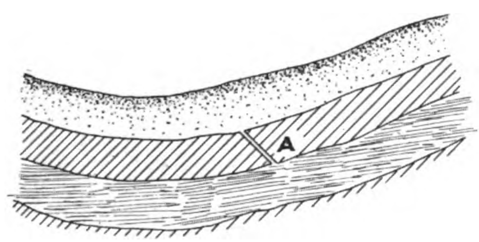

Fig. 17.—Stratification indicating Pollution of Main Springs.

pollution, is constructed to collect and store from two to seven days' supply. Where the source is well above the house the water may be supplied by gravitation through a pipe of either lead, cast-iron, or wrought-iron. If the water be sufficiently pure for domestic use, filtration at the source will not be necessary, but filters of the Pasteur, Doulton, or Berkefeld types should be attached to the taps from which drinking-water is drawn. When the character of the water is such as to render filtration desirable, a sand-filter should be constructed at the intake, and the raw water passed through the same before entering the storage tank.

Fig. 18 shows a section through the tanks, etc., of a small scheme for supplying a country house with water from a "deep-seated" spring. The water is conveyed from A through stoneware pipes, cement-jointed, to a detritus tank, B, whence it passes through a 3-in. cast-iron pipe, C, to the sand-filter D.

The filter is provided with an emptying pipe, E, for use during cleansing operations. The filtered water passes through the pipe F into the storage tank G, whence it is delivered to the house through a pipe of requisite capacity. The storage tank is provided with an overflow, H, and with an access cover, J. The bottom of the tank slopes from the outlet pipe to the inlet pipe to prevent sediment entering the draw-off pipe. The tank may be constructed of concrete from 6 ins. to 12 ins. thickness, according to requirements, with a 6-in. backing of

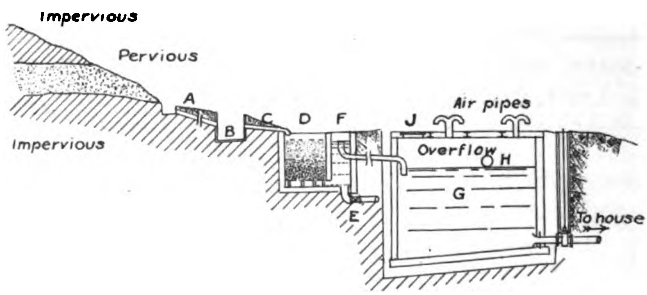

Fig. 18.—Spring-Water Supply, with Filter.

well-puddled clay, or it may be of engineering brick with an intermediate layer of sheet bitumen in the walls and floor. Air-pipes for ventilation purposes are necessary: these should be covered by suitable cowls or screens, to prevent vermin and dust gaining access to the stored water.

Where the height of the stream is insufficient to permit of a gravitation supply, the water will require to be lifted by a pump of a suitable type into a storage tank fixed in the highest part of the house.

Wells are classed in two groups:—

(1) Shallow wells;
(2) Deep wells.

Shallow Wells consist of shafts sunk into the surface layer of earth, for obtaining supplies from the water which lies above the first impervious stratum.

Deep Wells consist of shafts that are sunk through the surface stratum and continued into a water-bearing stratum beneath the first impervious bed.

The terms "deep" and "shallow" are used only in a

relative sense, and have no reference to the comparative depths of the two types of wells. In some cases shallow wells may be of greater depth than deep wells.

Fig. 19 shows a shallow well and a deep well respectively. The line A represents the mean level of the water in the surface layer. This line is varied in height by heavy rainfall and drought, also by excessive pumping of water from the well. The latter feature is often responsible for a temporary reversal of the direction of flow of the underground water, owing to the "cone of depression," which is formed on the water surface, extending to a varying radius from the centre of the well, as

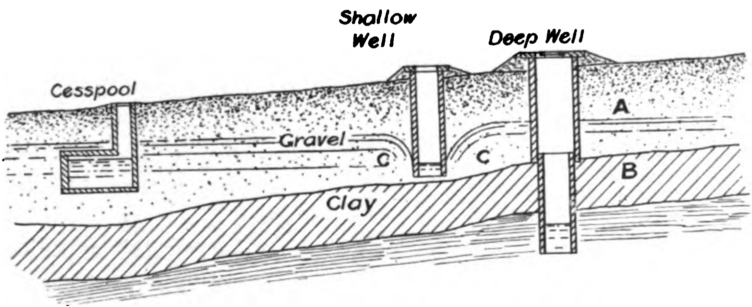

FIG. 19.—Pollution of Water in Shallow Well.

shown by the line C. This condition materially increases the risk of pollution of the water in some cases.

A pervious cesspool is shown some distance from the shallow well; under normal conditions the sewage which percolates therefrom into the subsoil would be carried away from the well owing to the natural inclination of the strata; but in the event of continuous pumping of water, a cone of depression is formed owing to the rate of flow through the porous earth being insufficient to maintain a normal water-level in the well. The pressure or head of water tending to cause a flow from the well towards the cesspool is temporarily reduced, and a current from the cesspool towards the well is liable to be set up, bringing soakage along with it.

Water from surface wells should always be looked upon with suspicion.

The use of shallow wells for the supply of water to villages and isolated houses is being discouraged by medical officers of

health and sanitary experts, owing to the excessive risks of pollution of the water percolating into such wells.

The "deep well," Fig. 19, is sunk through the two upper layers of earth, and enters the pervious layer situated immediately below the first impervious layer. The water in this stratum may be under pressure, or its normal level may be some distance below the impervious stratum, as shown by the dotted line B. This feature coupled with the amount of water required per day, also the effect of excessive pumping upon the water-level, will decide the depth to which the shaft must be continued into the lower pervious layer.

Construction of Wells.—The diameter of wells varies according to local requirements. Wells that are sunk for the purpose of obtaining town supplies vary in diameter from 8 to 20 ft. or more. They are circular in shape, and the depth is governed by the nature of the yield.

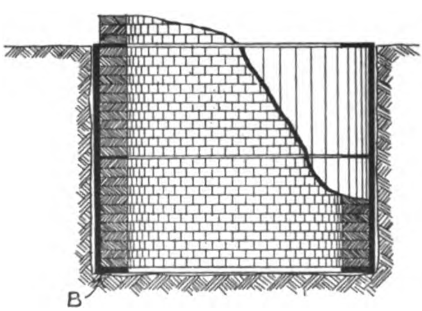

Fig. 20.—Mode of Construction of Shallow Well.

For "well" supplies to country houses shafts 4 to 8 ft. in diameter are adopted. The materials used for the construction of the shafts are: stone, brick, cast-iron, and pipes of stoneware.

The majority of wells are formed of bricks, usually of a hard type, but for surface wells large diameter pipes of stoneware are suitable. Cast-iron and also wrought-iron and steel tubes are used in some instances, but these are generally lined with bricks.

Care should be exercised when choosing a site, to avoid any possibility of future contamination of the water, and also to reduce the cost of the undertaking to a minimum.

The method generally adopted for sinking a brick shallow well consists in excavating a circular pit on the well site, of sufficient size to receive a cylinder formed of horizontal wooden rings and vertical staves of oak or elm. The inside of this cylinder is lined with bricks of the ordinary type, or specially

cut bricks. These are laid with their lengths radiating from the centre of the well, thus forming a circular wall 9 ins. thick.

Fig. 20 shows a sectional elevation of a wooden cylinder *in situ*. Excavation is proceeded with beneath the base B of the cylinder, which is gradually lowered as the earth is removed, care being taken to undermine equally around the base, to prevent tilting of the cylinder. In some instances temporary props are inserted to support the weight, or the cylinder is

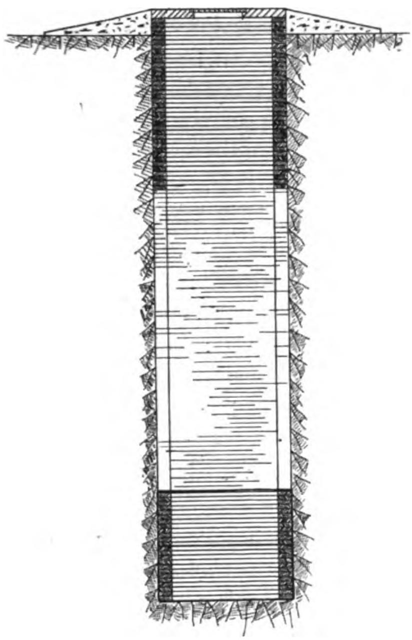

FIG. 21.—Shallow Well formed of Bricks.

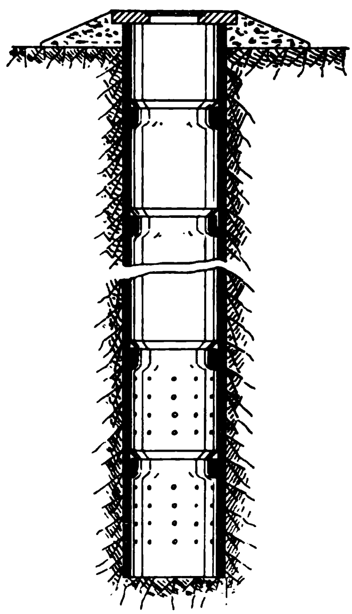

FIG. 22.—Shallow Well formed of Stoneware Tubes.

slung from the surface and lowered gradually, but in the case of small wells this procedure is not necessary. Additional rings of brickwork are added to the top as the work progresses, until the shaft is of sufficient depth.

For a depth of from 6 to 10 ft. below the surface the bricks should be laid in Portland cement mortar (1 cement, 2 sand), and the shaft should be raised to a height of 2 ft. above ground-level and surmounted by a holed stone provided with a cast-iron access cover. A crown or apron of Portland cement

shallow well, and the tubes are driven through the impervious stratum into a water-bearing stratum in which the water is under sufficient pressure to cause it to flow into the upper shaft, the well would be classed as a deep well. Fig. 26 shows a shallow well treated in this manner. The water in the third stratum passes, by reason of pressure, through the tubes into the brick shaft.

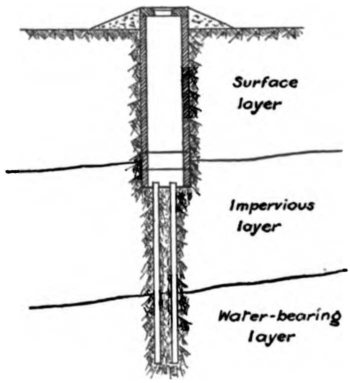

FIG. 26.—Construction of Deep Well with Driven Tubes.

Bore-holes are formed by piercing the various strata by means of suitable appliances and rendering available the portion of the rainfall that percolates to considerable depths in the earth. A not inconsiderable portion of the domestic water supplies in this country is obtained from bore-holes; also for manufacturing purposes it proves more economical in some cases than purchasing large quantities of water from the local water authorities. Usually the water obtained from bore-holes is of excellent quality, although its hardness is generally in excess of that obtaining in shallow and deep well waters, except when such wells occur in the chalk-beds.

The boring operations are carried out by firms who specialise in such work. The boring apparatus consists of a strong steel-wire rope, to one end of which the boring tool is attached along with two weights, one of which is much heavier than the other, the two being fixed a short distance apart. The heavier weight provides the striking force which drives the tool into the earth, whilst the smaller weight gyrates the rope and prevents the tool from continuously striking the earth in one position.

Variously shaped tools are used, according to the nature of the strata.

By means of a mechanical device attached to a derrick or framework fixed immediately over the bore-hole, the wire rope is raised and suddenly released.

The boring is lined with steel tubes, flush-jointed, which are varied in diameter according to local conditions. Tubes 36 ins. in diameter are sometimes used at the commencement of the boring, but owing to obstructions, etc., the diameter of the bore may be reduced by stages to 4 ins., and even less.

Fig. 27 shows a section through various strata in which a bore-hole is constructed. The water in the stratum is stored under sufficient pressure to cause it to flow from the mouth of

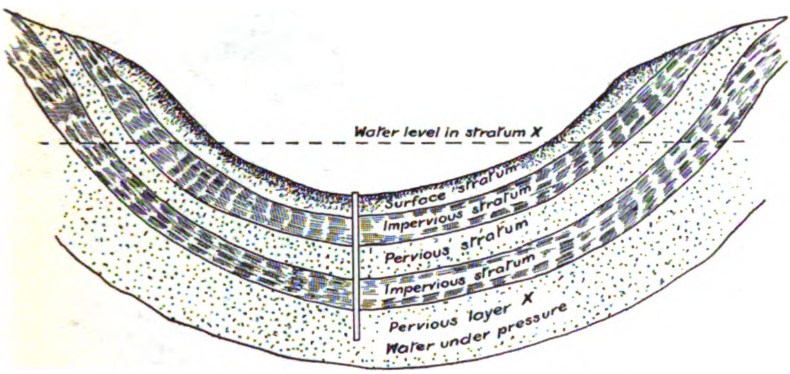

Fig. 27.—Section through Strata, indicating Water-level in Bore-hole.

the tube. When this condition obtains the bore-hole is spoken of as an **artesian well.**

Large quantities of water that have accumulated in the fissures, interstices, and subterranean caverns are frequently rendered available by borings, some of which yield upwards of a million gallons daily.

The depth to which the borings are taken varies between 100 and 2000 ft.

Collection and storage of the rainfall from impervious surfaces such as roofs, yards, and courts is occasionally adopted in country districts for domestic services other than drinking-water, and in some instances it also is used for the latter purpose.

Roof surfaces are generally chosen for the collection areas, and the water therefrom can be stored in a tank in the high part of the house. The various fittings throughout the premises are then supplied by gravitation.

A large portion of the organic matter which accumulates

on roof surfaces is conveyed by the rain-water into the storage tank, especially at the commencement of a heavy downpour. This is an objectionable feature, for the stored water gives off an unpleasant odour, especially when heated for use in baths,

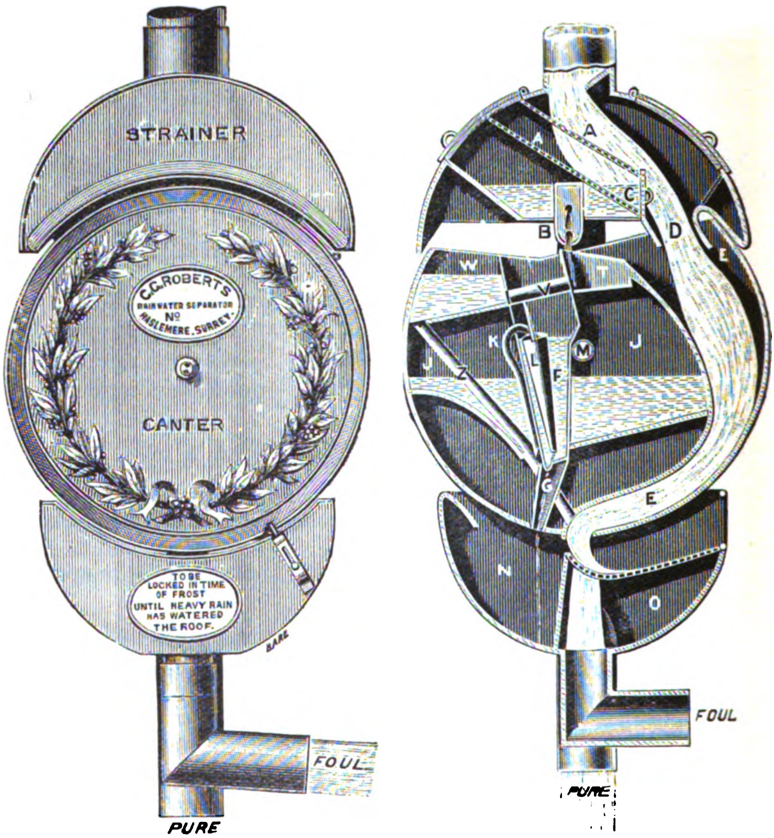

Fig. 28.—Rain-water Separator.

lavatories, and sinks. Such water is totally unfit for drinking or potable purposes.

In many instances the rain-water is conveyed by the ordinary fall pipes to an underground tank constructed in the vicinity of the building.

It is advisable to adopt an arrangement which will either reduce the amount of organic matter conveyed by the rain-water from the roofs, or eliminate it entirely before the water

passes into the distribution tank. Two methods are available for this purpose. One consists in fixing a device which will automatically divert the first portion of the rainfall, and discharge it into the foul-water drain. The roof-washings are thus prevented from mixing with the purer portion of the roof-water.

Fig. 28 shows a vertical section through Roberts' rain-water separator. This appliance consists of a series of chambers and small balancing tanks enclosed by a movable drum which turns about a central pivot, M, attached to a stationary part of the apparatus. The water enters through the screening chamber A, and passes through E into the foul-water chamber N, whence it passes by a special pipe to waste. In the compartment C a small adjustable sluice, B, allows a stream of water to pass into the chamber F, which, when full, overflows into the canting tank J. When a certain quantity of water has accumulated in J, the centre of gravity of the drum is altered, and a movement takes place which shifts the outlet of E from the chamber N to the chamber O. From the latter the water passes to the storage tank. When the flow from the roof ceases, the tank J is emptied by the siphon L, and the drum regains its normal position with the outlet of E over the foul-water chamber N.

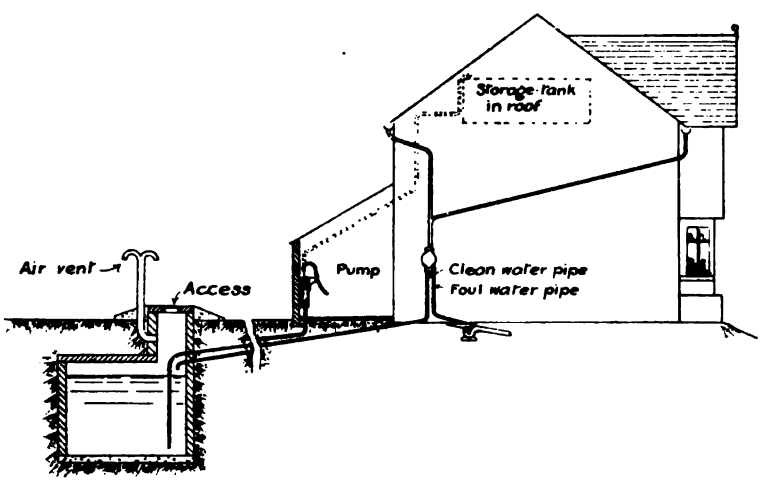

Fig. 29.—Scheme for Collection of Rain-water.

Fig. 29 shows the application of the rain-water separator to a rain-water storage system. The water is led to an underground

storage tank from the pure-water outlet, and is pumped as required into a distribution tank fixed in the high part of the house. Care should be taken to make the storage tank water-tight, and provision for ventilation of the enclosed space should be made. The top of the access shaft should be raised about 12 ins. above the surrounding earth and be banked with concrete.

If the rain-water is required for drinking and potable purposes, it must be filtered previous to delivery into the distribution tank. To effect this, one or more sand-filters are required in addition to a large storage tank for the raw water and a smaller one for the filtered water.

Fig. 30 shows a plan and sections of a scheme for the collection, storage, and filtration of rain-water for supplying a large country house with potable water. The rain-water is collected from the various roof-surfaces and conveyed through the main channels M M to the large storage tank, K. At R a horizontal type of rain-water separator is shown, but is not always used. The bottom of the tank K slopes towards the scour-pipe, where a sump is provided to facilitate the proper cleansing of the tank. The overflow is connected to the scour-pipe at the far side of the valve N. A pipe conveys the raw water through the valves D, C, on to the pair of filters H, J. The scour-pipe P from these filters is connected to the scour-pipe from the large storage tank. The outlets from the filters are guarded by the valves E and F, and enter a Y junction which conveys the water to the filtered water-storage tank G. This tank is provided with an emptying pipe, O, which joins the scour-pipe.

Great care is essential during the construction of the tanks and filters, to guard against the possibility of pollution of the stored water. The tank bottom can be of Portland cement concrete 6 ins. thick, and the walls of brick 14 to 18 ins. thickness, with a layer of sheet bitumen behind the inner 4½ ins. of brickwork. The bituminous sheeting must be continued over the bottom of the tank, and 3 ins. of brickwork should be placed above the sheeting. All brickwork must be set in cement mortar. Blue bricks should be used for the interior, and hard-burnt red bricks for the outer walls.

The respective capacities of tanks and filters will be governed by local conditions and requirements, assuming (*a*) that the total requirements of the house per diem = 500 gallons;

and (*b*) the collection area, *i.e.* the roof surface, is 140 ft. × 100 ft.; and (*c*) the mean annual rainfall = 50 ins.

The portion of the rainfall that can be stored will depend upon the amount which is rejected by the separator (if one be used) and

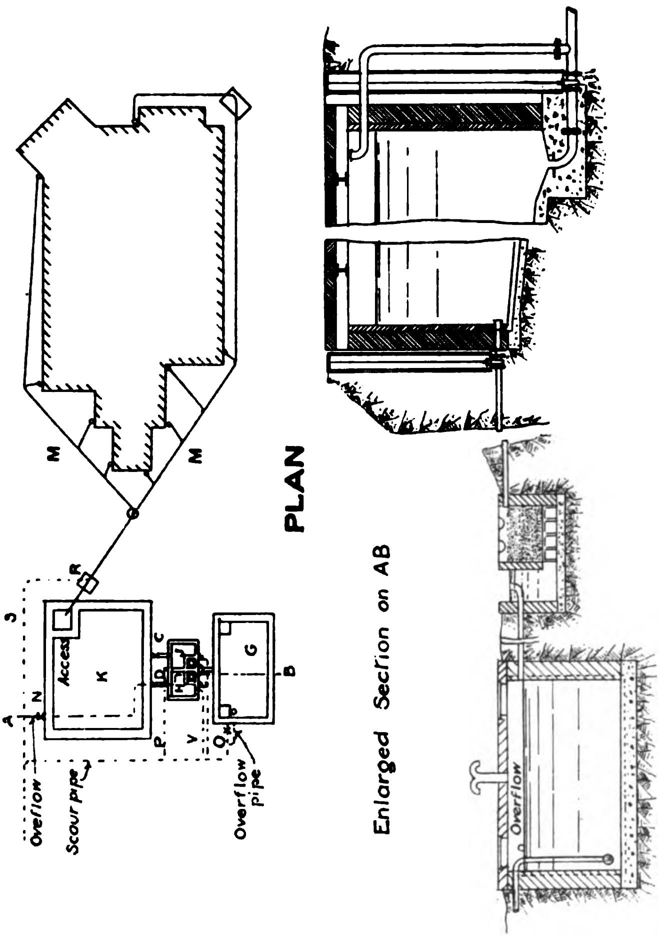

FIG. 30.—Scheme for Collection of Rain-water, with Filters, etc.

the quantity lost by evaporation. The latter quantity is fairly considerable during warm and windy weather, and especially if the rainfall be intermittent and also not heavy in character.

It is usual to allow from 6 to 8 ins. depth for evaporation, and assuming a reasonable amount—$\frac{1}{5}$ the total rainfall—to be

rejected by the separator—the total quantity available for storage is as follows:—

	Inches.		Inches.
Rejected by separator .	10	Total rainfall per annum .	50
Evaporation . . .	8	Deduct	18
	18	Available depth . .	32

(*Note.*—$6\frac{1}{4}$ galls. = 1 cub. ft.)

$$\frac{25}{4} \times \frac{140}{1} \times \frac{100}{1} \times \frac{32}{12} = 266{,}666 \text{ galls. per annum.}$$

Requirements per annum = $500 \times 365 = 182{,}500$ galls.; leaving a surplus of $266{,}666 - 182{,}500 = 84{,}166$ galls.

The amount to be stored varies in different districts as from 60 to 150 days. Assuming that 100 days' supply has to be stored, then the capacity of the storage tank

$$= \frac{100 \times 500}{6\frac{1}{4}} = 8000 \text{ cub. ft.}$$

Assuming the depth of the tank to be 10 ft. and the length 25 ft., the breadth

$$= \frac{8000}{25 \times 10} = 32 \text{ ft.}$$

The two filters should each have a surface area of 9 sq. ft. This will allow them to be worked under a slight head, and will give a highly efficient filtrate. Two pipes connect the filters to the scour-pipe, and provide for running the water from the filters to waste for a period of twenty-four hours after cleansing operations.

The duplication of the filters permits of cleansing being carried out without risk of a shortage of filtered water occurring.

The storage capacity of the filtered water-tank should be equal to three days' requirements. The capacity of the tank would then be—

$$\frac{500 \times 3}{6\frac{1}{4}} = 240 \text{ cub. ft.,}$$

which would be obtained by the following measurements:—
8 ft. × 6 ft. × 5 ft.

From this tank the water requires to be lifted by means of a pump into a storage tank fixed in the high part of the house.

It should be borne in mind that rain-water collected in country districts is soft, well aerated, and usually slightly acid. These features are responsible for the solvent action which rain-water has upon lead, iron, zinc, and copper. This action may be neutralised by allowing the water to come in contact with limestone or chalk; the CO_2 dissolved in the water combines with the lime carbonate, and the water is rendered alkaline. If care be taken regarding the use of the limestone, the solvent character of the water can be changed, but the water is liable to become "hard"—a feature which is considered objectionable. A hardness of several degrees is, however, preferable to a solvent property.

In rare instances special rain-water collection surfaces are provided by enclosing and carefully under-draining grass land. Great care is essential to prevent the subsoil water in the surrounding earth from entering the collection channels of the prepared area.

CHAPTER V

PUMPS, HYDRAULIC RAMS, AND THE AIR-LIFT

In the case of supplies that are situated below positions where the water is needed, appliances are required to raise the water to a desired height.

Pumps are generally used for this purpose. The following list defines the types of pumps:—

1. Suction pump.
2. Suction lift-pump (also known as the lift- and force-pump).
3. The ram or plunger pump.
4. The diaphragm pump.
5. The pulsometer pump.
6. The centrifugal pump.

The **Suction Pump** may be of lead, brass, or iron, and, in rare instances, of wood. It consists of a barrel or cylinder in which a bucket works. The bucket is provided with a valve, as also is the base of the barrel. Fig. 31 shows a sectional elevation of a lead suction pump. The barrel is formed of 4-in. lead pipe $\frac{1}{4}$ in. thick, and is lined with a copper tube to reduce the friction on the bucket and so lengthen the life of the pump. The lower part consists of a short piece of the same size of pipe worked into conoidal form to receive the valve box. The barrel and the tapered piece are joined by means of a plumber's wiped joint, and the copper lining is secured against movement by allowing a space of 1 in. between the apposing pipe ends, into which the solder flows during jointing operations and adheres to the tinned surface of the copper.

The bucket is of elm wood and is recessed around its lower outer surface to receive a band of leather about 4 ins. deep, which is secured to it by means of copper nails. A valve of

leather weighted with a disc of lead is attached to the upper surface of the aperture in the centre of the bucket. The bucket is attached to the operating rod.

The suction valve, which is of leather and weighted as in the case of the bucket valve, is attached to the valve box by copper nails. The valve box is secured in the tapered pipe by being wrapped tightly with a bulky packing of tallow-soaked hemp. It is hammered into position by means of a special form of rod. The whole of the appliance is supported by a strong wooden enclosure.

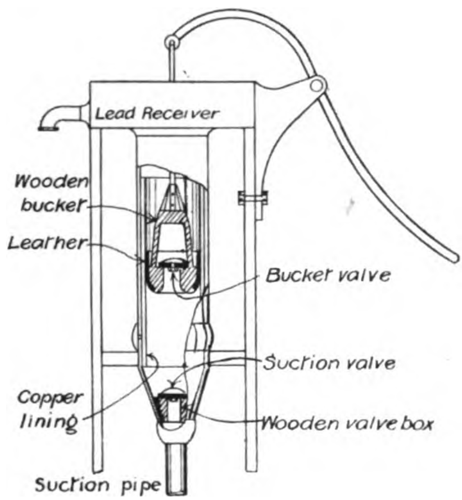

Fig. 31.—Lead Suction Pump.

This type of pump is frequently met with in country districts, and is occasionally adopted for new work in preference to pumps made of cast-iron.

The working of the suction pump is as follows:—A quantity of water is poured into the top of the barrel, and with the lower end of the suction pipe well under water the bucket is raised and lowered alternately; at each upstroke the air beneath the bucket is attenuated, the suction valve is forced open, and the pressure of the atmosphere forces a quantity of water up the suction pipe. When the bucket commences to descend, the suction valve closes and the bucket valve opens and allows a quantity of air to pass from below to above the

bucket. The repeated movements of the bucket eventually exhaust all the air from the suction pipe and the barrel, the space being filled by a column of water which is maintained by the pressure of the atmosphere acting on the free surface of the water in the well.

The working height of a suction pump above the water-level in well or tank is dependent upon the pressure of the atmosphere. Fig. 32 is a diagram illustrating this point. If the pump A be so fixed that the suction valve is 33 ft. above the water-level in the well, when the barometer gives a reading of 28 ins. of mercury, the pressure of the atmosphere per square inch would be sufficient to support a column of water 31·94 ft. in height. Beyond that height the water would not rise in the suction pipe, no matter how carefully or vigorously the pump-handle may be worked. If the barometric reading be increased by a change in atmospheric conditions to 30 ins. of mercury, the column of water which the weight of the atmosphere could support would be increased to 34 ft. (approximately), as shown by the following:—

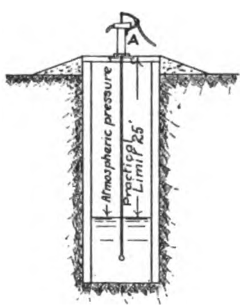

FIG. 32.
Suction Pump *in situ*, showing working limit.

$$30 \text{ ins. column of mercury} = \frac{30}{12} \text{ ft.}$$

$$\text{Specific gravity of mercury} = 13{\cdot}6$$

$$\therefore \quad \text{Column of water equal in height to } \frac{30}{12} \text{ ft. mercury}$$

$$= \frac{30}{12} \times \frac{13{\cdot}6}{1} = 34{\cdot}00 \text{ ft.}$$

It will thus be seen that under the increased pressure of the atmosphere the water would theoretically be forced to the top of the suction pipe.

Under practical conditions, however, it is not usual to fix a suction pump at a greater vertical distance than 25 ft. above the minimum water-level, owing to friction in the suction pipe, and the difficulty of maintaining the suction valves and the suction pipe and the joints connected therewith in a water- and gas-tight condition.

Fig. 33 shows a section though a pump formed of cast-iron, and having a copper lining. The suction and bucket valves may be of leather, rubber, or of brass or gun-metal. On the bucket a leather cup is provided, which is generally pressed into shape by machinery before use.

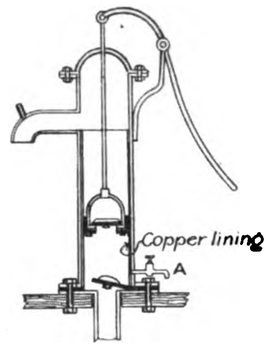

Fig. 33.—Cast-iron Suction Pump with Copper Lining.

This type of pump is suitable for raising small quantities of water. When fixed in exposed positions, a small cock, A, should be provided to empty the barrel during frosty weather. To accomplish this, the bucket valve would probably require to be unseated for a few seconds, or the cock opened and the pump-handle worked until the water has been displaced from the barrel.

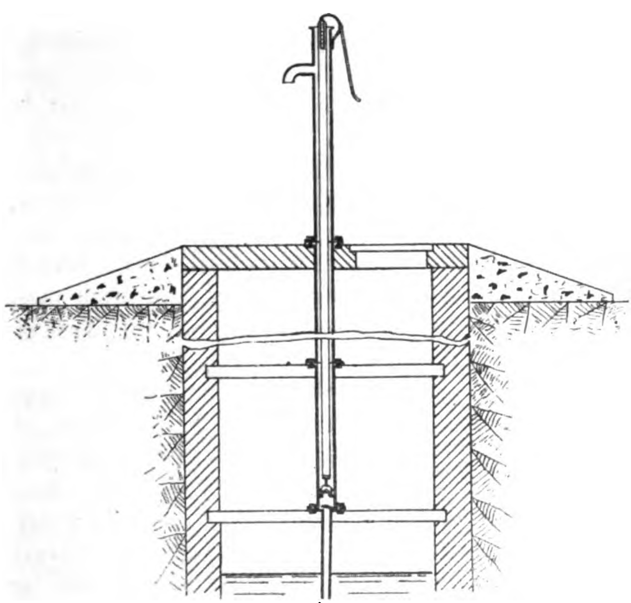

Fig. 34.—Long-barrelled Suction Pump.

This type of pump can be obtained made of brass, but it is much more expensive than the pump made of cast-iron.

In some instances the depth below the surface of the water-level in wells is too great to permit a suction pump of the ordinary type being used.

Fig. 34 shows a modification of the suction pump which is suitable for use under such circumstances, and where the water need only be raised to a convenient point a few feet above the ground.

It will be seen from the sketch that the pump barrel descends into the well to a considerable extent, thereby reducing the distance between the suction valve and the water-level. The pump rod is usually of elm wood, as iron being specifically heavier would increase the effort required to raise the water during the upstroke of the bucket.

The Suction Lift-Pump is generally used where it is necessary to raise the water to a point situated some height above the pump. There are many forms of this appliance, one of which is shown in Fig. 35. It differs from the suction pump in that its upper end is enclosed, and the bucket rod passes through a packing gland, A. The water is delivered through the arm B and past the valve C into the delivery pipe D.

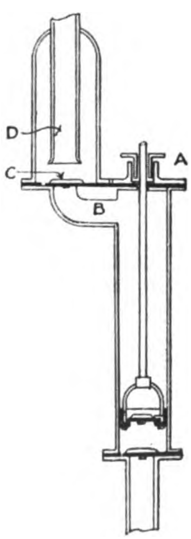

Fig. 35.
Suction Lift-Pump (section through).

This type of pump is usually made either of cast-iron lined with copper, or of brass or gunmetal. The valves are generally of brass with leather or rubber facings. Although brass valves are often used, they are not so serviceable for this class of work as those faced with leather.

The working of the suction lift-pump is as follows:—When the barrel is charged with water, on the upstroke of the pump bucket the suction and delivery valves open, the bucket valve closes, and the water above the bucket is lifted into the delivery pipe. Air-pressure forces water up the suction pipe and into the space in the barrel below the bucket. On the downstroke the bucket valve opens and the suction and delivery valves close, water passes through the bucket valve, and on the upstroke is lifted into the delivery pipe.

Fixing of the Suction Lift-Pump.—If local conditions will permit of the pump being fixed on the surface, it may be secured to an oak board or to an iron framework, as shown by Fig. 36.

The former method is generally adopted in the case of small pumps where there is a wall to which the board may be secured.

Iron framework support is provided in the case of double-barrelled pumps or pumps of large diameter.

Fig. 36.
Suction Lift-Pump attached to Board.

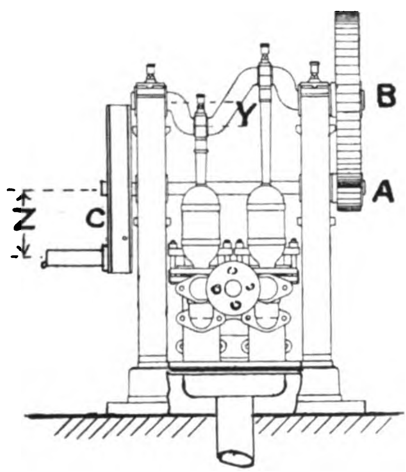

Fig. 37.—Geared Double-barrelled Pump.

A rotary motion is generally used for applying force to the pump bucket. If it is required to lift the water to a considerable height, a geared pump can be used to give the relative speeds of the driving wheel and crank shaft necessary if the pump is to be worked by manual labour. Fig. 37 shows a double-barrelled geared suction lift-pump. The relative speeds of the driving wheel C and the crank shaft Y are to each other as the ratio of the diameters of the toothed wheels A and B.

$$\begin{aligned} \text{If the diameter of A} &= 18 \text{ ins.} \\ \text{and} \quad ,, \quad ,, \quad \text{B} &= 6 \;\; ,, \\ \text{the relative rotations of C and Y} &= A:B \\ &= 18:6 \\ &= 3:1 \end{aligned}$$

Thus the wheel C will be rotated thrice to complete one cycle of the crank shaft Y.

It will be observed that the suction and delivery pipes are common to both barrels. The double-barrelled pump has a distinct mechanical advantage over the single-barrelled type. During the working of the pump the water in the suction and delivery pipes is kept in constant motion; inertia once overcome is not again in evidence during the continuous working of the pump.

In many cases the depth of the water-level below the surface of the earth renders it necessary to fix the pump in the well.

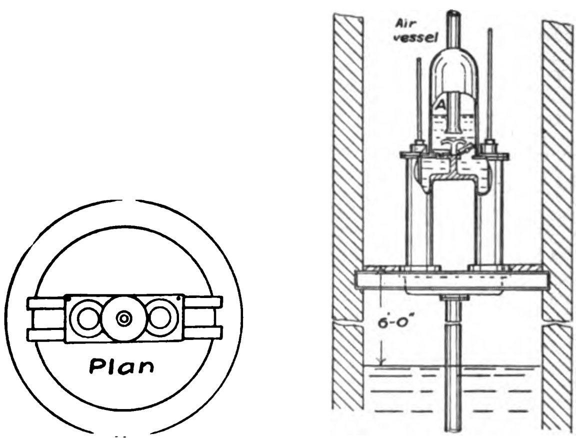

Fig. 38.—Double-barrelled Pump in Well.

For this purpose a strong rigid platform is essential to which the pump can be secured. Cross-beams of oak covered with oak lagging are suitable. Rolled steel or iron beams well coated with Dr Angus Smith's composition, fixed across the well with their ends firmly embedded in the wall of the well, are satisfactory supports for the attachment of the pump. A floor of oak lags over the lower beams is useful to provide a secure foothold for workmen during repairs to the pump.

Fig. 38 shows the plan and sectional elevation of a double-barrelled pump fixed in a well. The pump is worked by means of rods of wrought-iron attached to a double-cranked shaft on the surface. Roller guides are provided at 6 ft. intervals

to prevent the rods from buckling. Fig. 39 shows plan and elevation of a pair of antifriction rollers attached to an oak stay. The rollers are generally made of brass and the framework of cast-iron.

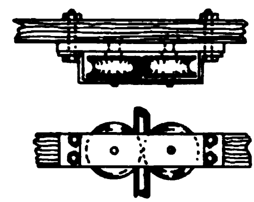

Fig. 39.—Antifriction Rollers for Pump Rod.

When necessary to place a pump in a well, it should be fixed as near to the water as possible. The distance observed between the pump and the water is generally 6 ft.

Air-vessels used in connection with pumps are chambers formed so as to hold a quantity of air which acts as an elastic body in opposition to a body of water, thereby reducing shock, stress, friction, and the amount of energy required to work the pump.

They may be fixed on the delivery pipes and on the suction pipes. In all cases they should be placed as near to the pump as possible so that the full effect of the elastic property of the air may be available. The air-vessel shown in Fig. 38 consists of a 12-in. diameter tube resting over the "delivery" valves attached to the two barrels. The upper end is closed and receives the delivery pipe, which passes into it to a point about 4 ins. above its base. When the pumps are working, the water is lifted through the delivery valves and enters the air-vessel, where it compresses the air. The air reacts and forces the water up the delivery pipe. It should be remembered that the reaction of an elastic substance is always equal to the original force which produced the stress. In the case of a single-barrelled pump, the water in the delivery pipe is kept in constant motion during pumping. This considerably reduces the stress upon the working parts of the pump, and eliminates the possibility of damage thereto by shock or water-hammer. Moreover, the energy necessary to work the pump is minimised, owing to the fact that the retarding force due to inertia of the water in the delivery pipe has to be overcome only at the commencement of pumping.

In the absence of an air-vessel the water would be forced through the delivery pipe at a much higher velocity than the speed of the piston, owing to the smaller area of the delivery pipe as compared with that of the pump barrel. The increase

of velocity and the surmounting of the inertia of the water in the delivery pipe at each stroke would add materially to the energy required to work the pump in addition to unduly stressing the parts.

Where used on delivery pipes, it is advisable to provide each air-vessel with two small cocks, one at the top and one at the base of the vessel. During the working of the pump the air being under pressure is gradually absorbed by the water, owing to the increased solvent power of the water (as regards gases), due to increase of pressure. The periodic opening of the two cocks and the closing of the valve, which should be fixed on the delivery pipe just above the vessel, will result in the recharging of the air-vessel with air.

The capacity of an air-vessel should be governed by local conditions. If the delivery pipe be of considerable length, comparatively small in diameter, and possessing numerous bends, and if the height to which the water is to be delivered above the pump exceeds 30 ft., the air-vessel should have a capacity of not less than twice that of the pump barrel. For easier conditions a capacity of one and a half that of the pump barrel will be sufficient.

Suction pumps and suction lift-pumps are often fixed an appreciable distance from the wells or tanks to which they are connected by long lengths of suction pipes. In many cases this distance is so great that the pumps can only be worked with great difficulty and undue forcing of the working parts. The long train of water in the suction pipe of a pump fixed under such conditions is lifted by atmospheric pressure. The velocity of the water through the suction pipe towards the barrel will be governed entirely by this force. In such cases, if the bucket be raised quickly, a vacuum is formed beneath it. At the termination of the upstroke the bucket recoils sharply. In addition to the damage to the pump that may result from this action, the amount of water raised is not compatible with the general efficiency ratio of such a pump. These defects can be minimised by fixing an air-vessel of sufficient capacity on the suction pipe near to the pump barrel, as shown by Fig. 40.

After fixing the pump the barrel is primed, *i.e.* filled with water and the handle worked; air is extracted from the

suction pipe and air-vessel until the water is forced by atmospheric pressure past the valve B, and partly charges A. At each upstroke of the piston the air in the air-vessel is attenuated and the water-level lowered; during the downstroke the elastic force of the imprisoned air reacts and water enters A from the suction pipe. There is a continuous flow of water into A during the working of the piston owing to the air being in a state of tension, the force of which exceeds that of the pressure due to the head of water in the suction pipe.

It is rarely necessary to provide means for recharging the

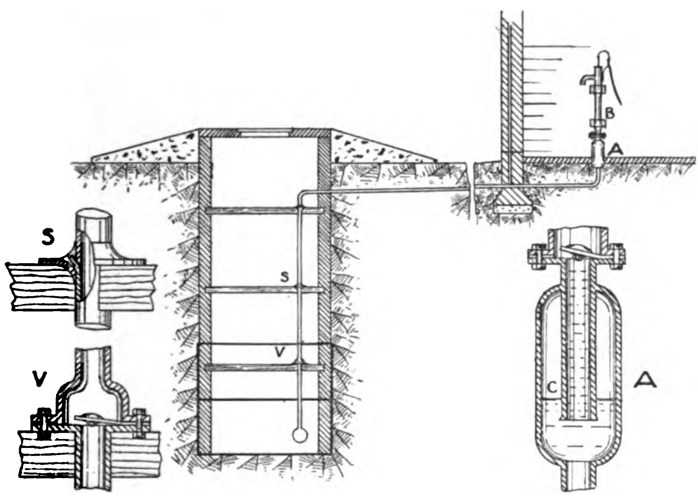

FIG. 40.—Treatment of Long Suction Pipes.

air-vessel, as the pressure on the water-surface C is much less than that on the water-surface in the well; therefore air and other gases are released from the water and pass into A.

The air-vessel may be formed of either copper, cast-iron, or lead.

Suction pipes are generally of lead or wrought-iron (plain or galvanised), but where soft water has to be conveyed, pipes of cast-iron properly coated with Dr Angus Smith's composition are to be preferred. In all cases great care should be taken during the laying and jointing of the pipes to prevent defects due to subsidence, insufficient support in the well, or insecure jointing.

The slightest defect in the suction pipe may be responsible (when the pump is not being worked) for the admission of air, and the consequent escape of water therefrom. An additional amount of energy is then required to charge the suction pipe at each pumping operation. Slight defects are often difficult to locate; they can usually be discovered by a careful examination of the pipe under working conditions—the insuction of air even in minute quantities will cause a slight hissing sound.

If the pipe be of copper, the joints should be screwed and sweated; and if of cast-iron, the faced flange joint with india-rubber packing will give the best results. Lead pipe should be jointed by the plumber's wiped joint. For wrought-iron the screwed joint is the best.

Adequate support must be provided where the pipe passes down the well. For lead pipe, a soldered flange on a cross-bearer support, as shown at S, Fig. 40, will give good results.

For pipes of iron or copper, clips bolted together and secured to the wooden cross-stays by either bolts or carriage screws will suffice.

The lower end of the suction pipe is generally provided with a perforated enlargement, usually known as a "wine bore."

Suction-pipe retaining Valves are occasionally used where the length of this pipe is considerable. A valve of this type should be fixed in the well at a convenient point above the maximum water-level. These valves are useful in case of defects occurring in the suction pipes, as they retain the water and prevent it passing back into the well. Fig. 40 shows a valve *in situ* and in detail.

A Double-action Pump having a solid bucket is shown in Fig. 41. A single suction pipe is provided which delivers water to the top and bottom of the barrel through the valves V_3 and V_4. The valves V_1 and V_2 guard against a reflux from the common delivery pipe A. The working of this pump is as follows:—On the upstroke of the bucket B the water in the upper part of the barrel is forced past V_1 and into the delivery pipe. At the same time the air is drawn up from under B, and the water follows, fills the space and passes from the suction pipe C through valve V_4. During the downstroke this water is forced through V_2, and the upper part of the barrel is

again charged from C. It will thus be seen that the water in the suction and delivery pipes is in constant motion during pumping; moreover, the weight of the pump rod is available on the downstroke to assist in raising the water, and the energy necessary to raise the rod is thereby negatived.

This type of pump is suitable where a large diameter barrel is necessary. It works very smoothly, but there should be an air-vessel fixed at the commencement of the delivery pipe.

The watertight packing of the solid bucket may consist of two opposing leather cups, or of a metallic packing of antifriction metal.

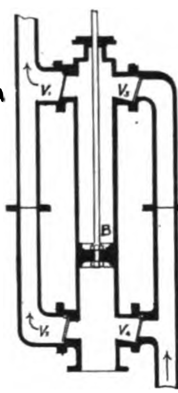

FIG. 41.—Double-action Plunger Pump.

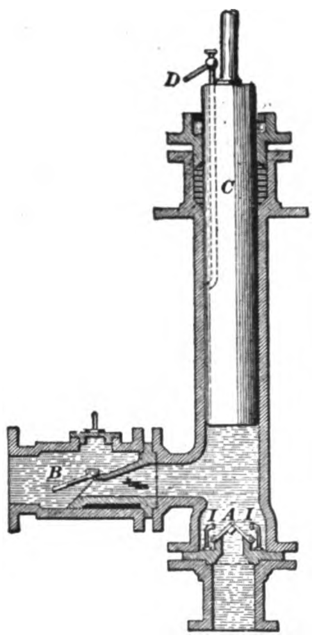

FIG. 42.—Ram Pump.

For pumps of comparatively small diameter the former is better, but for the larger pumps the latter is generally used.

The Ram or Plunger Pump shown in Fig 42 is often fixed to deliver water against great pressure. The ram C does not fit the barrel tightly. When working under normal conditions the upstroke of the plunger or ram causes a vacuum in the barrel, which is followed by an influx of water from the suction pipe through the valves at A; on the downstroke the water is displaced past the valve B into the delivery pipe, the valves at A closing meanwhile. The dotted line shown on the ram and terminating at the cock D is provided to allow of the

escape of air, which, if retained, would, owing to its elasticity, throw the pump out of action, or materially reduce its efficiency.

This type of pump is useful in connection with high-pressure hydraulic work where pressures of ½ ton and more per square inch are needed.

The force-pump commonly used by plumbers and others for unstopping pipes is similar in principle to the foregoing appliance.

The Diaphragm Pump is shown in Fig. 43. It consists of a comparatively large diameter barrel to the top of which a disc, A, of thick sheet rubber is secured having in the centre a valve, B. The suction valve C rests on the suction pipe, which is attached to the base of the barrel. When the handle is worked, the air is gradually exhausted from the barrel and water takes its place, passing through from valve C. The rubber diaphragm acts as a bucket and lifts the water, which passes through B into the outlet.

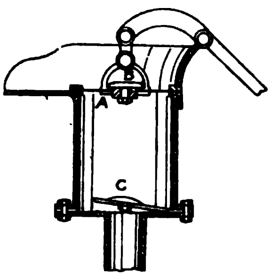

Fig. 43.—Diaphragm Pump.

This type of pump is often used by contractors for clearing water from trenches, shafts, or cuttings. It has a short stroke, and is capable of lifting large quantities of water.

The Centrifugal Pump derives its name from the nature of the force by which it raises water. It consists of a series of curved wings, blades, or arms, radiating from a common centre that forms a shaft, enclosed by a cast-iron casing. Fig. 44 shows a sketch of a centrifugal pump.

The centre of the revolving bladed wheel forms the commencement of the suction pipe. The wheel revolves at a high velocity, and the water entering at the centre is thrown with considerable force towards the outlet. The velocity of the water as it leaves the wheel is sufficient to raise it to a definite height.

The pump and suction pipe require to be filled with water before starting the pump. If the air be not exhausted therefrom the movement of the propelling wheel will only result in the churning up of the enclosed air without effecting a raising

of the water. When a pump is fixed several feet above the mean water-level a foot valve is necessary, and also an arrangement for charging the pump with water. Where possible, the pumps should be fixed with the shafts in a vertical position, and as near to the water as possible. For high lifts a series of pumps are required from two to six in number. The water is delivered from the first pump into the casing of the second pump, where its initial velocity is considerably increased, and

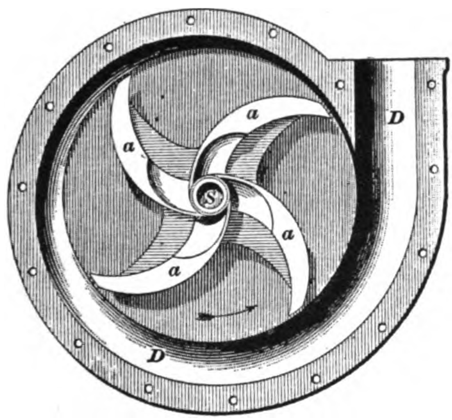

Fig. 44.—Centrifugal Pump.

thence it is delivered in succession through the whole of the series of pumps. In certain "multi-stage" centrifugal pumps the water leaves the casing of the last pump of the series at a high velocity which is sufficient to raise it to a height of more than 1000 feet.

Owing to the absence of valves in their construction these pumps are useful for raising large quantities of dirty water as well as clean water.

The Power used in connection with the working of pumps varies according to local conditions and the effective duty required from each machine. In many cases human energy is relied upon, and where the demand is not excessive and the total height to which the water has to be lifted does not exceed 60 ft., it is not unreasonable to supply the power through such agency. It often happens, however, that the maximum requirements are such that other sources of energy have to be requisitioned.

The principal sources of energy that are used for driving or working pumps are:—

Electricity.
Steam.
Gas or oil.
Hot air.
Wind.
Water.
Animal and horse power (on farms, etc.).

Where a current of electricity is available at a reasonable cost, it is undoubtedly economical to use it. A motor may be installed and coupled to the pump either by gearing as shown in Fig. 45, or by pulleys and a belt. In the case of a centrifugal pump the motor can be connected directly to the shaft of the impulse wheel.

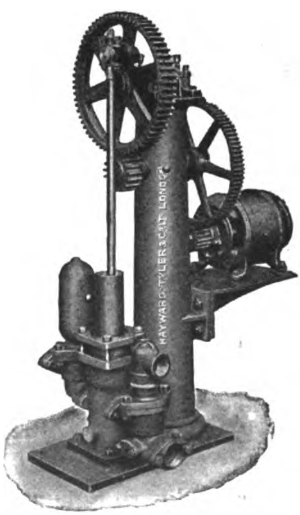

Fig. 45.—Hayward & Tyler's Motor-driven Pump.

Fig. 46.—Hayward & Tyler's Hot-air Engine and Pump.

The adoption of a steam engine may be advantageous where steam is generated for other purposes, if the additional duty will not necessitate an extension of the existing plant. If such

be necessary it would probably be more economical to adopt electricity or gas, if either of these be within reach at a reasonable cost.

Gas can in many cases be applied for this purpose. Coal-gas can be obtained at a reasonable cost in towns, but in villages and in the case of an isolated country house, small petrol motors can be economically adapted to provide the necessary energy for pumping.

Oil engines, especially the Diesel type, are also useful for the purpose and require very little attention.

Hot-air engines require more attention as regards starting and regulating, especially in connection with stoking arrangements where coke or coal is used.

Fig. 46 shows a hot-air engine and pump suitable for a country house. It can be worked economically, and is obtainable in sizes of ½-horse power and upwards.

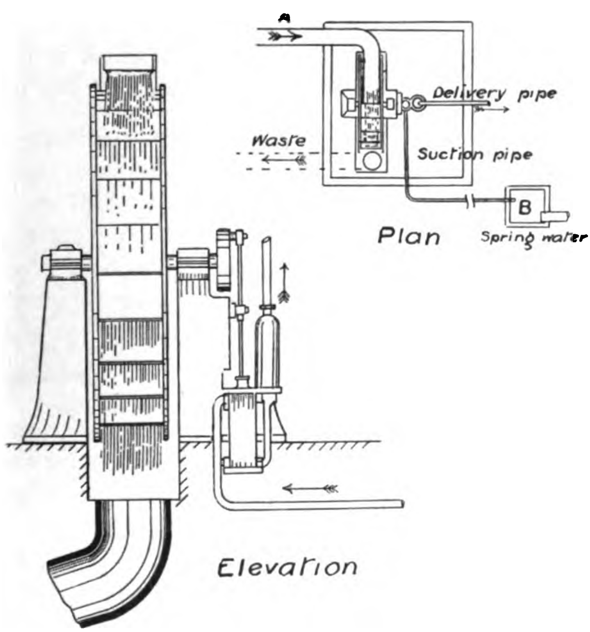

Fig. 47.—Plan and Elevation of Pump worked by Water-Wheel.

In country districts the force of the wind is utilised through the medium of wind engines that are harnessed to the pumps

Care is necessary when selecting the sites for such appliances so that they may have the full benefit of the force of the prevailing winds.

In the case of a country house where an abundant quantity of water from a stream is available, sufficient energy can be economically obtained to work the pumps by fixing either low-pressure turbines or water-wheels, and conveying to them a supply of water through a conduit.

Fig. 47 shows a plan and an elevation of a simple arrangement whereby the water from a stream can be made to drive a water-wheel, which in turn works a double-action suction lift-pump.

Water-wheels are of three principal types:—

(1) Undershot;
(2) Breast;
(3) Overshot.

The undershot water-wheel is supplied with water near its base. The water supply to the breast wheel is delivered at the centre of the wheel, and in the case of the overshot wheel the supply enters at the top.

Fig. 48 shows the three types.

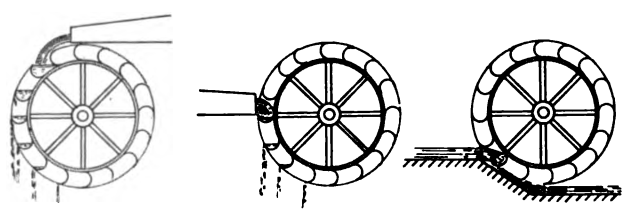

Fig. 48.—Water-Wheels.

The relative efficiency of each type is:—

(1) Overshot, 60 to 80 per cent.;
(2) Breast, 40 to 50 per cent.;
(3) Undershot, 25 to 40 per cent.

These appliances are gradually being displaced by modern turbines, which are so designed as to obtain a much higher efficiency when fixed under the same conditions.

The wheel shown in Fig. 47 is of the overshot type. The

water is led to the wheel through the conduit A, which may be of earthenware or cast-iron pipes, or simply in the form of an open cutting. The waste water is conveyed away to the stream through a conduit of earthenware pipes.

The double-action pump lifts the pure spring water collected in the tank B to a storage cistern fixed in a high part of the house.

In the case of farms or country houses where horses are available, horse-gearing arrangements can be adopted for providing the necessary power to work the pumps.

The Ashley pump shown in Fig. 49 is of peculiar construction. It is suitable for raising water from deep wells or from borings. There are several examples of this type of pump, but the notable feature is that the working parts are all embodied in the bucket, which can easily be removed for repair purposes.

The pump must be fixed below minimum water-level.

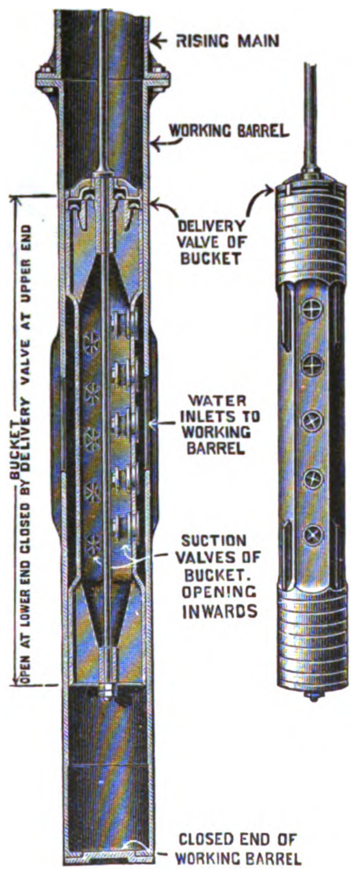

Fig. 49.—Ashley Pump.

The suction valves are fixed on the inside of the tubular bucket, which is provided with metallic packings around its upper and lower portions. The top of the bucket forms the seatings for two or more delivery valves. On the upstroke these valves close and the numerous suction valves open, allowing water to pass into the cylinder. When the downstroke occurs the metallic packing on the lower end of the bucket, which fits tightly in the bottom of the cylinder, prevents the water escaping from the tubular bucket, and the

suction valves closing compel the water to pass through the bucket valves into the rising main.

If repairs are necessary to the valves, the bucket may be removed and replaced without difficulty.

The Pulsometer Pump shown in section in Fig. 50 possesses certain peculiar features that make its use advan-

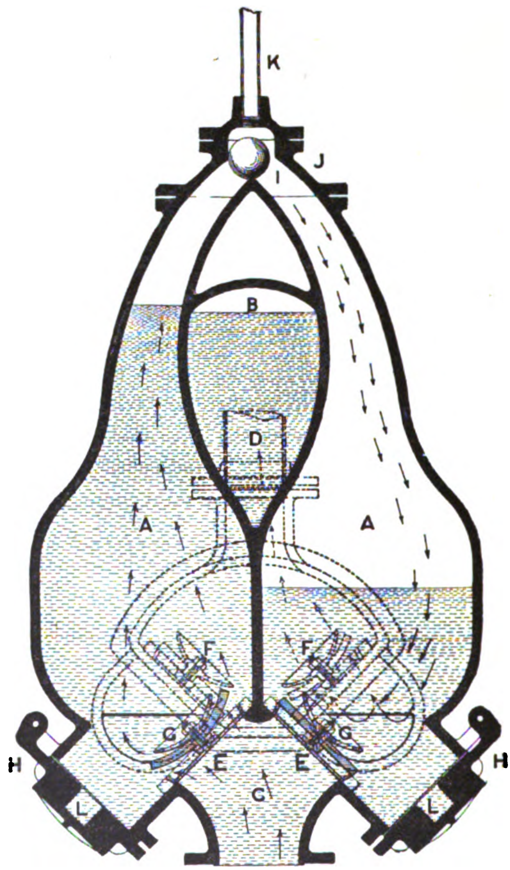

Fig. 50.—Pulsometer Pump.

tageous under exceptional conditions. It is worked by a supply of steam under a suitable pressure which is governed by the requirements of each case. The pump consists of a cast-iron body divided into several compartments with attachments for suction and delivery pipes at C and D respectively.

The two tapering chambers A A communicate with the suction and delivery pipes through the valves E E and F F. The upper ends of these chambers converge and communicate with the steam pipe K, and are provided with turned and faced gunmetal seatings upon which the oscillating ball valve I rests alternately during the working of the pump. An air valve is provided in each chamber and in the air-vessel.

The working of the pump depends upon the admittance of a supply of steam to the chambers A A alternately, at sufficient pressure to force the water therefrom and raise it to a requisite height through the delivery pipe. The subsequent condensation of the steam in one chamber causes the spherical valve I to fall over the neck J, and a partial vacuum is formed which is responsible for a flow of water into the chamber through the suction valve E. A small quantity of air is admitted to the chamber A through an air valve (not shown in the illustration). Meanwhile the opposite chamber is emptied, and the valve I is pulled over by the condensation of the steam. Consequently a supply of steam is admitted to the water-charged chamber, and forces its content into the delivery pipe. The air-cushion acts as an elastic buffer and prevents impact of the steam and water, and also acts as a cushion during the changing over of the spherical valve.

The alternate filling and emptying of the chambers A A goes on incessantly, so long as a steam supply is available along with a sufficient quantity of water.

This pump can be obtained in different sizes, with capacities varying from 1000 to 150,000 galls. per hour. It is useful for temporary works, and in positions where the use of a piston type of pump would entail a considerable outlay.

The Air Lift-Pump is used principally in connection with the raising of water from bore-holes and deep wells on a large scale.

The principle of this method is the injection of compressed air into a column of water enclosed in a vertical tube sunk to a requisite depth in the water contained in the well or bore-hole. The air-supply is so regulated that it mixes intimately with the water in the rising main, or causes the formation of thin laminæ of air and water, the aggregate weight per unit volume of which is considerably less than that of the water surround-

ing the pipe. Consequently, the former is forced up the delivery tube in a continuous stream.

The following conditions have to be complied with to ensure satisfactory working of an air lift-pump:—

1st. The lower end of the delivery pipe where the air is injected must terminate at a greater distance below the surface of the water in the well than the height of the lift above the minimum water-level.

2nd. The air-compressing machinery must be able to give an adequate supply under sufficient pressure to ensure a constant delivery of air. If the pressure or the volume delivered be insufficient, the lifting action will develop a cycle comprising a rush of water from the delivery pipe followed by a period of rest during which the air accumulates and then suddenly discharges.

This action results in a considerable loss of energy by the escape of air at the mouth of the delivery pipe.

3rd. The submersion depth of the delivery tube below the minimum water-level in the bore-hole should be not less than one and a half times the height of the lift above the free surface A.

4th. An increase of efficiency accompanies a further depth of submersion of the tube B.

5th. The rate of flow should not exceed 5 ft. per second, otherwise a considerable reduction of efficiency will result, due to friction losses.

Again, the condition of the air-compressor will influence the results. In general, it may be stated that an efficiency of from 25 to 50 per cent. can be obtained.

The arrangement for discharging the air into the water should be so constructed that the air will be divided into a number of small globules not exceeding $\frac{1}{4}$ in. in diameter, in which state it will be more readily diffused and absorbed.

Fig. 51 shows the outline of an air lift-pump *in situ.*

An air-compressing plant is necessary to provide a continuous supply of compressed air, and a special delivery nozzle is required to admit the air quietly to the delivery pipe.

In some cases the bore-hole is made to act as the delivery tube, and the air pipe is passed into it to a requisite depth. The top of the tube of the bore-hole is connected to a conduit

of sufficient capacity, which conveys the water to a storage tank or reservoir. By this arrangement the total capacity of the boring is available for the delivery of water, with the exception of the space occupied by the air pipe.

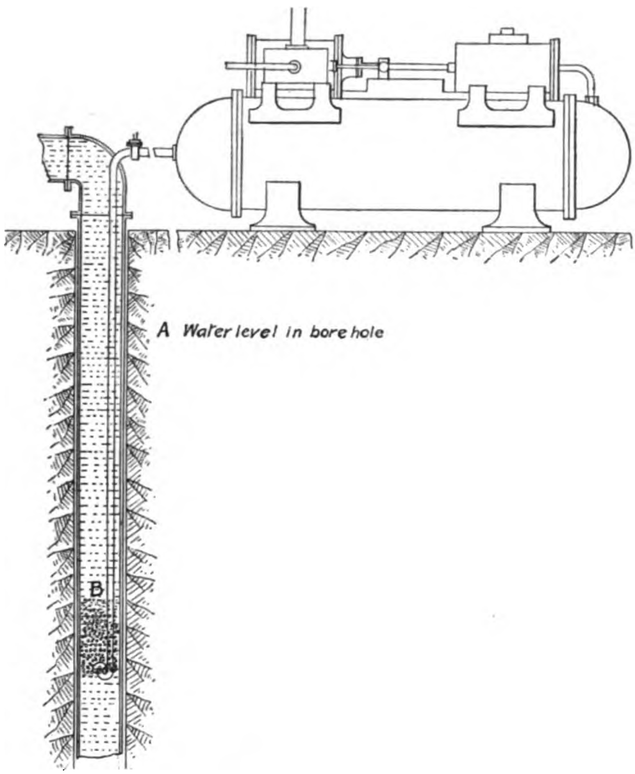

Fig. 51.—Air-compressor with Air-lift.

The Hydraulic Ram is an appliance used for raising water from a low level to a higher level by the energy developed in a mass of water falling from a given height through a conduit connected with the ram. A small portion of the water which enters the ram is raised to a definite height above the ram, whilst the major portion passes to waste.

A machine of this kind is very useful where a large quantity of water is available throughout the year in the form of a continuous spring, a stream, pond, or river. In country districts where there are no organised systems of water supply,

private houses, hamlets, and small villages may be economically provided with a gravitation supply by the use of hydraulic rams of sufficient capacity.

In all cases where it is deemed advisable to fix one of these appliances, the adequacy and continuity of the volume of available water should be carefully determined before deciding to proceed with the work. Close investigation of the contour of the ground in the vicinity of the stream is also necessary with a view to obtaining a sufficient head of water to work the machine and the requisite inclination for draining away the waste water.

Hydraulic rams are of two principal types:—

1*st*. One which raises a portion of the water that is used to work the ram.

2*nd*. One which is worked by impure water and raises a purer water obtained from an entirely different source.

The former is sometimes known as the "single-acting" hydraulic ram, and is adopted for domestic water supply only where there is an abundant and continuous supply of pure water.

The latter is known as the "double-acting" hydraulic ram. It is useful in districts where the quantity of drinking or potable water of a satisfactory quality is limited, but where there is impure water in abundance.

Fig. 52 shows a scheme for supplying a country house with water from a stream, using a hydraulic ram for raising the water to a storage tank fixed in an upper portion of the building.

A pipe is inserted to convey water from the stream to a straining chamber, in which the heavier solids and the lighter debris such as pieces of wood, etc., are retained. The balancing tank must be made watertight. Concrete or brick walls and floor with a backing of well-puddled clay 9 ins. thick will give satisfaction. The top of this tank should be covered to exclude the light, otherwise low forms of vegetable life will develop and pollute the water. From the balancing tank a "drive pipe" is laid to the ram, which is housed in a small building of brick roofed in to protect the ram from atmospheric influences. The total inclination of this pipe in the example submitted is 15 ft., but this amount is not always available. A delivery

pipe conveys the water from the ram to a storage tank fixed in a high part of the dwelling-house. The tank is 85 ft. above the ram and 70 ft. above the stream. The waste-water conduit

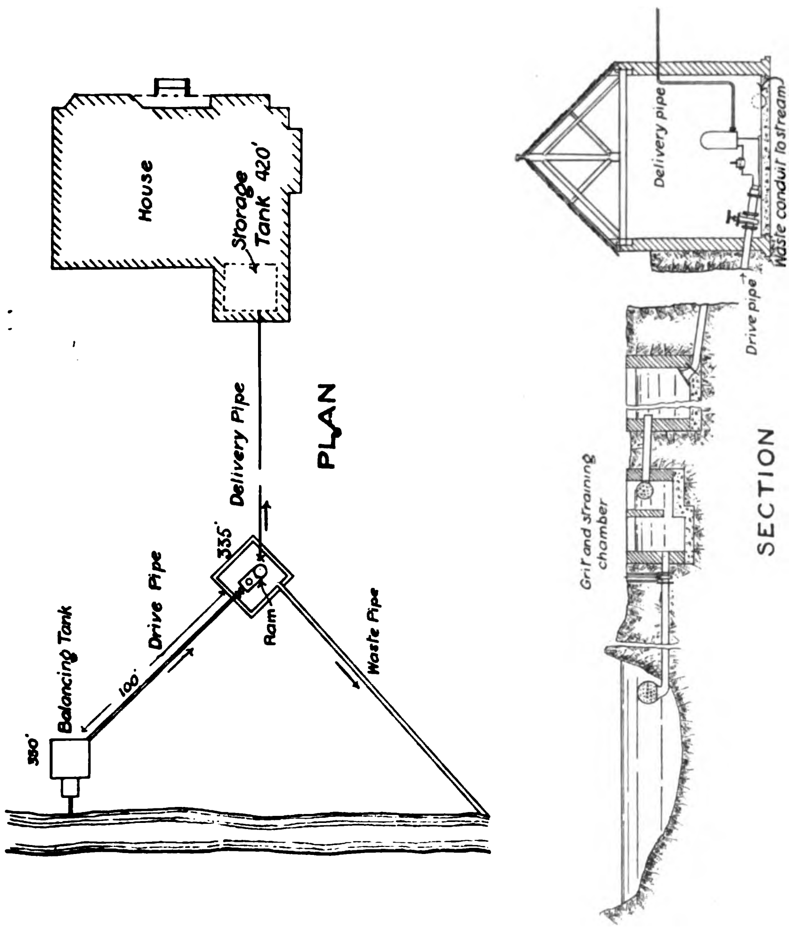

FIG. 52.—Water supplied from Stream to House by Hydraulic Ram.

conveys the spent water to the stream at a point 18 ft. below the level, where the water is taken to the balancing tank.

It will thus be seen that with a head of water of 15 ft. a quantity of water is raised to a point 85 ft. above the ram.

Fig. 53 shows a view, etc., of one type of hydraulic ram. The water is led to the ram through the injector or drive pipe D.P. The dash valve D.V. is of either gunmetal or phosphor

bronze, and the retaining or delivery valve C.V. is of the grid type with a rubber ring or washer. The delivery pipe is connected to the flange R.P., and the cap M.H. provides for

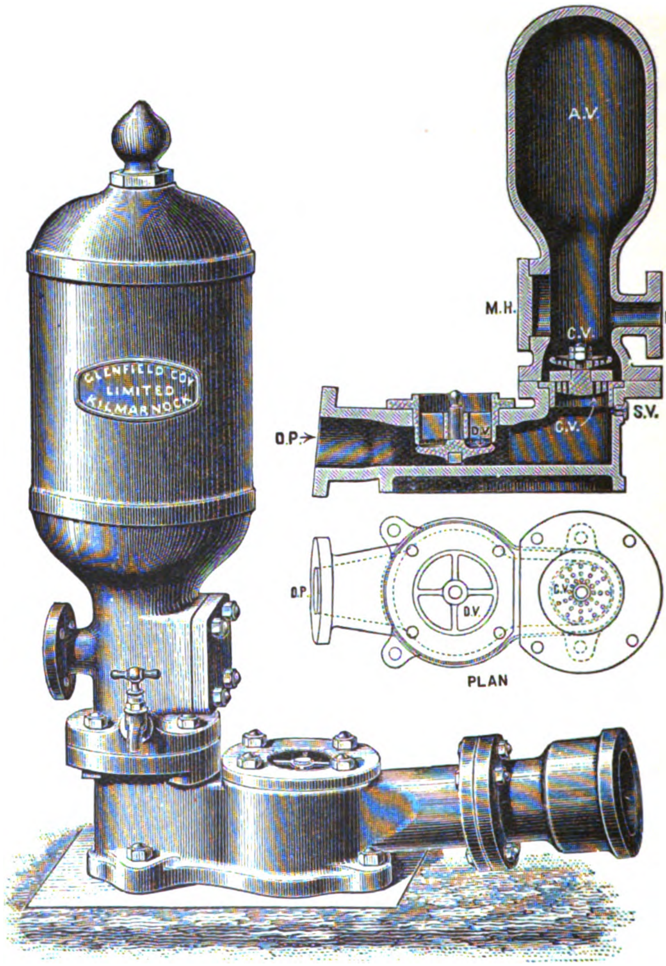

Fig. 53.—Hydraulic Ram.

access to the valve C.V. for repair purposes. Immediately beneath this valve is an air-hole or "snifter," S.V., which admits air for the purpose of maintaining an air-cushion in the air-vessel A.V.

The working of the ram is as follows:—When the drive pipe and ram are fully charged, the water rises in the delivery pipe to a height equal to the head of water above the ram. The weight of the dash valve is so balanced that the head of water will be sufficient to keep the valve closed unless force be exerted to open it.

If the valve be forced downwards a quantity of water will escape, and thus cause the train of water in the drive pipe to come into motion; the escaping water exerts an upward thrust on the under surface of the valve, causing it to close quickly. The moving train of water in the drive or injector pipe is brought to a pause, and its kinetic energy is expended on the whole of the inner surface of the ram. A portion of the water is forced past the valve C.V. into the air-vessel. The concussion thus produced is immediately followed by a reaction or rebound, during which a partial vacuum is formed in the body of the ram, a small quantity of air is drawn in through S.V., and the dash valve falls owing to the recoil of the water which passes in a peristaltic wave through the drive pipe. On the falling of the dash valve water again escapes, and the concussion caused by the closing of the valve is again followed by a recoil. The alternate concussion and recoil goes on incessantly so long as the ram is in working order and is supplied with a requisite volume of water. At each beat of the dash valve a small quantity of water enters the air-vessel and compresses the air therein, which in turn reacts and forces the water in a continuous stream through the delivery pipe.

The valve S.V. maintains the necessary volume of air in the air-vessel. The air is being continuously absorbed, owing to the greater solvency of air in water under pressure.

It is essential that the working parts of the ram be of the best materials. The dash valve and its seating are subjected to considerable wearing action, owing to the severe impact of the two surfaces. The retaining valve is in some cases formed of a spherically shaped piece of gunmetal resting on a circular seating and enclosed by a cagework of the same metal. Valves of this type have given satisfaction, owing to their great strength and the even wearing action which takes place, due to their rotating each time that they are lifted or displaced by the passing water.

The mushroom form of valve gives good results, but it is occasionally distorted by the severity of the repeated impact with its seating, unless it be of exceptional strength and thickness.

The following points should be observed when arranging for and fixing hydraulic rams:—

1. The length of the drive pipe should be not less than the vertical height of the delivery pipe above the ram.
2. The "snifter" should be free from any obstruction, and of sufficient capacity to keep the air-vessel fully charged with air.
3. Valves should be provided at the points where the drive and delivery pipes join the ram, to allow of repairs being undertaken without emptying these pipes.
4. The ram should be fixed in such a position that will allow the waste water to drain away, and thus avoid flooding of the ram shelter.
5. A rigid base of concrete or stone must be prepared, to which the ram must be securely bolted.
6. The adequacy of the volume of water available and its sufficiency to meet all requirements should be determined previous to deciding the size of the ram.

Failure to obtain satisfactory working of a hydraulic ram may be due to the following causes: insufficient volume of air in the air-vessel. This causes a gradual quickening of the beat of the dash valve, which finally ceases entirely. It may be remedied by attention to the "snifter," or in the case of a badly designed ram, by a periodic recharge of the air-vessel.

Defective Valves.—Attention should be given to this point by overhauling the ram twice a year.

Shortness of Drive Pipe.—This is a fruitful source of failure. If the drive pipe is too short, the peristaltic wave caused by the recoil of the water in the ram will travel through the pipe and the disturbance will be seen in the water in the supply tank. Where the delivery pipe is abnormally long the length of the drive pipe should be increased to 1½ times the height of the delivery. Too small a working head above the ram, with a comparatively high lift, reduce the efficiency of the ram. It is not advisable to work a ram with less than a 4-ft. head

of water, and the maximum height to which the water is to be raised should not exceed twenty-five times the "head" of the supply to the ram.

One form of the second type of ram, which is worked by impure water and raises pure water, is shown in section by Fig. 54.

The lower part of the appliance is practically the same as that of the ram shown in Fig. 53 as regards construction, but in the place of the delivery valve a double-ended plunger piston

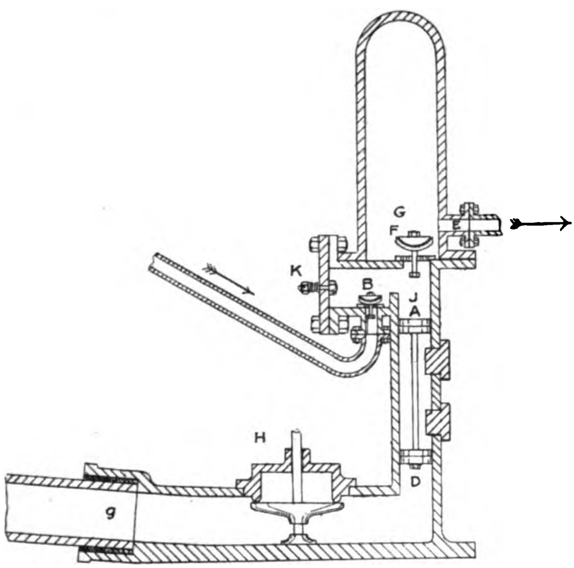

FIG. 54.—Hydraulic Ram worked by Impure Water.

is provided, of which the upper face A has a leather cup that works in a tight-fitting barrel. The pure water enters the barrel past the valve B, and is delivered into the air-vessel G by the upward thrust of the ram A D. The air in the air-vessel forces the water along the delivery pipe E.

The action of the appliance is as follows:—When the water enters the body of the ram by way of the drive pipe *g*, the dash valve H closes suddenly, and the concussion set up operating on the piston face D lifts the piston A D to the extent of its stroke. A portion of the pure water resting on

the face A is forced past the valve F and enters the air-vessel, whence it is discharged into the delivery pipe.

When the reaction occurs the dash valve H opens and the reduced pressure on D causes the piston A D to descend, the latter action being aided by the weight of the piston. A partial vacuum is formed in the pump-chamber J, and water enters from the suction pipe. This action is continuously repeated whilst the ram is in working order. The small valve K is provided with a compression spring which may be adjusted so as to admit a small quantity of air to the chamber J each time the piston A D descends. This is necessary to replenish the air removed from the chamber G by the increased solvent action of the water under pressure,

The ram should be fixed as nearly level (below it if possible) with the mean level of the water in the pure-water tank as possible, and the length of the suction pipe should be reduced to a minimum. Where the latter feature cannot be obtained, an air-vessel must be provided on the suction pipe.

Particulars relating to Glenfield Kennedy's Direct-acting Rams.

Diameter of Drive Pipe.	Diameter of Rising Pipe.	Quantity Raised 100 ft. high in twenty-four hours according to Fall.
1 in. to 1½ ins.	½ in. to ¾ in.	100 to 500
1¾ ins. to 2 "	1 in.	200 to 1,000
2½ " to 3 "	1½ ins. to 2 ins.	500 to 3,000
3½ " to 4 "	2 ins.	800 to 5,000
5 " to 6 "	2½ ins.	1,200 to 9,000
7 " to 9 "	3 ins. to 4 ins.	5,000 to 40,000

The discharging capacities of these rams depend upon several factors, the chief of which are: the working head, the length and diameter of the drive pipe, the height and diameter of the delivery pipe, and the condition of the valves.

The area of the dash valve varies from two to four times that of the supply or drive pipe.

The number of beats per minute varies from 60 to about

200, and is governed by the head of water above the ram, the delivery head, and the weight and area of the valve.

It has been estimated that the full cycle is made up as follows:—

	Per cent.	
Time required for opening . .	7·5	of the time required for the full cycle.
" " closing . .	7·5	
" during which the valve remains closed . . .	25	
" during which the valve is full open . . .	60	

The amount delivered will depend upon the size of the ram, the supply head, and the delivery head, and may be expressed as follows:—

Efficiency $K = \frac{qh}{QH}$

and the quantity passed through the delivery pipe $= K\frac{QH}{h}$

in which
q = quantity delivered against a head, h (in feet).
Q = quantity supplied from the tank under a head, H, to the ram.
K = efficiency, which varies from 25 per cent. to 65 per cent.
h = delivery head in feet.
H = supply head in feet.

Example.—A ram is supplied with 8000 gallons of water per day under a head of 10 feet, and raises 500 gallons to a height of 150 feet above the ram; determine the percentage efficiency.

$$K = \frac{qh}{QH}$$

$$= \frac{500 \times 150}{8000 \times 10}$$

$$\text{percentage efficiency} = \frac{5}{8} \times \frac{100}{1}$$

$$= 62\tfrac{1}{2} \text{ per cent.}$$

Example.—The efficiency of a ram is reputed to be 60 per cent. It is supplied with 4000 gallons of water per day under a head of 12 ft., and is required to raise water against a

delivery head of 120 ft. Determine the amount raised per hour.

$$q = K\frac{QH}{h}$$

$$= \frac{60}{100} \times \frac{4000 \times 12}{120}$$

$$= 240 \text{ galls. per day}$$

$$\therefore \quad \text{quantity per hour} = \frac{240}{24} = 10 \text{ galls. per hour.}$$

Experiments have proved that the nearer the factors H and h are to a state of equality, the higher will be the efficiency; and conversely, as the ratio between these two factors increases, the efficiency decreases.

With a supply head of from 3 to 6 ft., and a delivery head of from four to six times this, the efficiency may reach 80 per cent.; but when the ratio between these approaches 30 or 40 to 1, the efficiency will be in the vicinity of from 15 to 25 per cent.

Discharge from Pumps.—The theoretical quantity of water that is swept out of the barrel of a pump at each effective stroke is equal to the cross-sectional area of the bucket or plunger (according to type of pump considered), multiplied by the length of stroke.

Volume (V) $= \dfrac{\pi D^2}{4} \times L$, in which L = length of stroke.

D = diameter of pump barrel.
N = number of strokes per minute.
V = volume in cub. feet.

The volume in gallons delivered by a given number of strokes $= 6\frac{1}{4} \times V \times N$.

It is found in practice that the actual quantity delivered is much less than the theoretical value. This is due to slow-closing valves, leaky valves, slip at the bucket, waterlogged air-vessel, want of air-vessel on suction pipe, and excessive lengths of suction and delivery pipes. The value of the loss varies with different types of pumps.

In defective pumps it will frequently be as high as 40 per

cent. of the theoretical quantity, and in those properly constructed and maintained in a good condition the loss will rarely exceed 15 per cent.

The percentage efficiency is the ratio between the theoretical value and the actual value × 100;

$$i.e., \quad \frac{\text{actual quantity}}{\text{theoretical quantity}} \times 100.$$

Example.—A single-action pump working thirty strokes per minute, 18-in. stroke, has a diameter of $3\frac{1}{2}$ ins.; find the discharge in gallons per hour. Percentage efficiency = 90.

$$\begin{aligned} \text{Gallons per stroke} &= \cdot 9 \times 6\cdot 25\, \pi R^2 L \\ \text{,, \quad minute} &= \cdot 9 \times 6\cdot 25\, \pi R^2 L \times 30 \\ \text{,, \quad hour} &= \cdot 9 \times 6\cdot 25 \times \pi R^2 L \times 30 \times 60 \\ &= \frac{\cdot 9}{1} \times \frac{6\cdot 25}{1} \times \frac{22}{7} \times \frac{7}{48} \times \frac{7}{48} \times \frac{3}{2} \times \frac{30}{1} \times \frac{60}{1} \\ &= 1015 \text{ galls. (approx.).} \end{aligned}$$

In the case of a pump of the double-action type throwing water at each up and down stroke respectively, the quantity delivered will be twice that obtained from a single-action pump of the same dimensions working at the same rate and having the same efficiency.

To determine the size of pump required to deliver a given number of gallons per hour, it is necessary to assume a length of stroke and the number of strokes per minute.

If 1200 gallons per hour be required, and the pump is assumed to work at 25 strokes per minute, the amount swept out of the barrel at each stroke

$$\begin{aligned} &= \frac{\text{gallons}}{6\cdot 24 \times N \times 60} \\ &= \frac{1200}{6\cdot 24 \times 30 \times 60} \\ &= \frac{1}{9\cdot 36} \text{ cub. ft.} \\ &= 184\cdot 6 \text{ cub. ins.} \end{aligned}$$

Assuming the length of stroke to be 15 ins., and

the efficiency to be 90 per cent., the area of the pump bucket

$$= \frac{184 \cdot 6}{15} \times \frac{10}{9}$$

$$= 13 \cdot 7 \text{ sq. ins. (approx.)}$$

$$\text{Diameter} = 2\sqrt{\frac{\text{area}}{\pi}}$$

$$= 2\sqrt{\frac{13 \cdot 7}{\frac{22}{7}}}$$

$$= 4 \cdot 09 \text{ ins.}$$

In this case a 4-in. pump with a 15-in. stroke would be satisfactory.

The total resistance to be overcome during the lifting stroke of the bucket is due—1*st*, to the total "head" of water on the bucket; 2*nd*, the friction set up in the suction and delivery pipes; and 3*rd*, the friction in the packing gland, the bearings, and in the barrel.

The "effective" work done in foot-pounds per minute equals the weight (in pounds) of water raised per minute multiplied by the "head" of water against which the lifting force of the bucket is exerted.

Example.—What is the effective work in foot-pounds per minute done through a pump 6 ins. diameter, working 35 strokes per minute, length of stroke 21 ins., 80 per cent. efficiency, if the delivery point be 120 ft. above the water in the well (1 cub. ft. of water weighs 62·4 lbs.)?

Weight, in pounds, of water raised per minute

$$= \frac{80}{100} \times 62 \cdot 4 \, \pi R^2 LNH$$

$$= \frac{80}{100} \times \frac{62 \cdot 4}{1} \times \frac{22}{7} \times \frac{1}{4} \times \frac{1}{4} \times \frac{21}{12} \times \frac{35}{1} \times \frac{120}{1}$$

$$= 72{,}072 \text{ ft.-lbs. per minute.}$$

One horse-power is equivalent to the energy necessary to raise 33,000 lbs. through a height of 1 ft. in one minute.

If it be required to express the energy absorbed, in terms of "horse-power," then (adding 25 per cent. for friction)

$$\text{h.p.} = \frac{72{,}072 + \left(70{,}072 \times \frac{25}{100}\right)}{33{,}000}$$

$$= \frac{90{,}090}{33{,}000}$$

$$= 3 \text{ horse-power (approx.).}$$

Where hand-power is relied upon it is necessary in some cases to use a geared pump, as shown in Fig. 37, p. 61, in which the mechanical advantage gained may be expressed as—

1*st*. The ratio of the lever Z to the crank Y.

2*nd*. The ratio of the circumference of A to the circumference of B, the total advantage

$$= \frac{Z}{Y} \times \frac{\text{circumference of A}}{\text{circumference of B}}$$

$$\text{or} \qquad = \frac{Z}{Y} \times \frac{\text{diameter of A}}{\text{diameter of B}}$$

Example.—In a double-action geared pump the total weight on the bucket is 250 lbs. The handle Z is 18 ins. long, and Y is 9 ins. The gear wheels A and B are 15 ins. and 5 ins. diameter respectively. Find the weight required on the handle to counterbalance that on the bucket (neglecting friction).

$$W = \frac{250}{\frac{Z}{Y} \times \frac{\text{Diameter of A}}{\text{Diameter of B}}} = \frac{250}{1} \times \frac{9}{18} \times \frac{5}{15}$$

$$= 42 \text{ lbs. (approx.).}$$

CHAPTER VI

THE DISTRIBUTION AND STORAGE OF WATER

ALL organised systems of water supplies to communities are invariably arranged on the "gravitation" principle, so that each house is assured an adequate daily supply under pressure without resorting to pumping. The latter condition obtains even in cases where the original supply is derived from wells or other sources that are situated below the distribution area. Under such circumstances the water is pumped into a service reservoir situated some distance above the highest building to be supplied.

Where upland surface water is used, storage reservoirs are constructed to hold from 100 to 200 days' supply. One or more "service" reservoirs are provided in commanding situations near to the distribution area. The storage capacity of a service reservoir is varied according to local conditions, but is usually equal to from one to seven days' requirements.

From the service reservoir the water is delivered to the districts through leading and subsidiary mains that communicate with service mains, from which pipes of small diameter are led to the buildings.

The mains are usually of cast iron or wrought steel, riveted. The latter is only used in the case of mains of large diameter.

Cast-iron water-mains must be formed of vertically cast pipes.

Standard weights of pipes of various diameters are generally adopted. The following table indicates the sizes, weights, and thicknesses of vertically cast pipes:—

3″ to 14″ dia., 9 ft. long plus socket; 15″ to 24″, 12 ft. long plus socket.

Internal dia.	Thickness.	Average Weight of each Pipe.			Thickness.	Average Weight of each Pipe.			Thickness.	Average Weight of each Pipe.			Thickness.	Average Weight of each Pipe.		
Ins.	Ins.	Cwts.	Qrs.	Lbs.	Ins.	Cwts.	Qrs.	Lbs.	Ins.	Cwts.	Qrs.	Lbs.	Ins.	Cwts.	Qrs.	Lbs.
3	·368	1	0	10	·375	1	0	14	·400	1	0	23	·428	1	1	4
4	·375	1	1	24	·397	1	2	6	·420	1	2	16	·443	1	2	26
5	·405	1	3	22	·428	2	0	9	·451	2	0	22	·473	2	1	6
6	·437	2	2	0	·459	2	2	14	·481	2	3	0	·502	2	3	14
7	·450	3	0	0	·473	3	0	18	·496	3	1	8	·518	3	1	20
8	·460	3	2	0	·485	3	2	21	·510	3	3	14	·535	4	0	17
9	·480	4	0	7	·506	4	1	3	·532	4	2	0	·560	4	3	0
10	·500	4	2	7	·527	4	3	7	·555	5	0	7	·582	5	1	7
12	·560	6	1	0	·594	6	2	14	·627	7	0	0	·661	7	1	14
14	·625	8	0	0	·660	8	1	24	·695	8	3	21	·725	9	1	10
15	·637	11	2	2	·676	12	0	27	·715	13	0	2	·750	13	2	18
16	·650	12	2	0	·693	13	1	9	·736	14	0	20	·780	15	0	4
18	·687	14	3	8	·733	15	3	8	·777	16	2	0	·822	18	0	1
20	·725	17	1	24	·777	18	2	22	·829	19	3	13	·880	21	0	0
21	·740	18	1	23	·793	19	3	3	·846	21	0	18	·897	22	1	14
22	·755	19	2	0	·809	20	3	16	·868	22	1	10	·914	23	2	7
24	·787	22	1	0	·842	24	0	8	·897	25	2	16	·942	27	0	26

The ordinary spigot and socket joint is generally used on cast-iron water-mains, although in some cases the turned and bored joint is adopted.

The material used for the former joint should be virgin pig-lead; after caulking in the gaskin compactly the remaining annular space, which need not exceed 2 ins. in depth, should be carefully filled with molten lead. When the joint is cold, the lead should be carefully and evenly compacted with the aid of a broad-ended caulking tool and heavy hammer. This process is essential to the formation of a watertight joint, as the lead on cooling contracts to a greater extent than the iron, thus leaving a space between the two.

When preparing the socket for the reception of the molten lead the grummet of clay or other material (Fig. 55) is formed in such a manner as to allow a small surplus of lead to project, which is caulked flush with the face of the socket.

The turned and bored joint (Fig. 56) is also used, especially where the mains will be subjected to an abnormal pressure. Before placing the pipes in position the turned surfaces are coated with red-lead paint, Portland cement, or a mixture of bitumen, and then forced together. It is usual to fill the annular recess with molten lead when the pipes are laid.

The rigid character of this joint is a disadvantage in positions where there is liability to subsidence.

Its use is advocated in the case of waterlogged trenches, owing to the danger attending the use of molten lead for jointing purposes. Lead in a molten state when brought into contact with wet or even slightly damp surfaces is violently dispersed in all directions by the sudden generation of steam, and the workmen run grave risks of being badly burnt.

When used under such conditions, the shallow recess is either filled with Portland cement or is left untouched.

In waterlogged trenches the ordinary spigot and socket joint can be laid with safety, by using instead of molten lead,

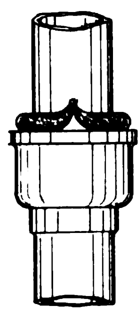

Fig. 55.—Pipe Joint for Cast-iron Water-Main.

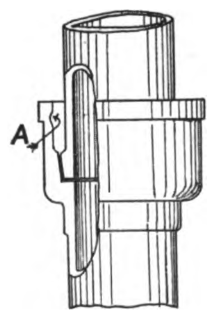

Fig. 56.—Turned and Bored Pipe Joint.

"lead wool," which consists of thin strands of lead twisted together into rope form. It is caulked into the jointing space in the manner adopted for securing gaskin, and a watertight and otherwise satisfactory joint results.

All joints must be made in the trenches with the pipes and fittings resting in their permanent positions; the custom obtaining in certain districts of jointing three or four pipes and lowering them into the trenches should not be permitted, as it is impossible to avoid disturbance of the caulked joints, and leakage often results therefrom.

Water-mains should be laid at such a depth as will secure for them immunity from the action of frost.

In the roads and streets of towns and cities the damage due to the vibration caused by heavy vehicular traffic would be greatly reduced if the pipes were laid at a minimum depth of

4 ft.; there would also then be no risk, in this country, of freezing occurring.

When arranging the sizes and routes for the pipes to be laid in any district, future expansion of the area and the direction which it is likely to take are considered. The scheme is devised in such a manner that the various pipe lines intercommunicate, to avoid "dead" ends, whilst ensuring a greater supply to any section of the mains than would obtain if the branch service mains were not interconnected. Moreover, when repairs are necessary the defective portion only need be shut off, thus minimising the inconvenience to the consumers.

A well-designed distribution scheme has all its various sections under complete control by means of suitable valves provided at advantageous points on the pipe lines and at the junctions.

Sluice valves are the most satisfactory for this purpose. Fig. 57 shows part sections of a socketed sluice valve and a

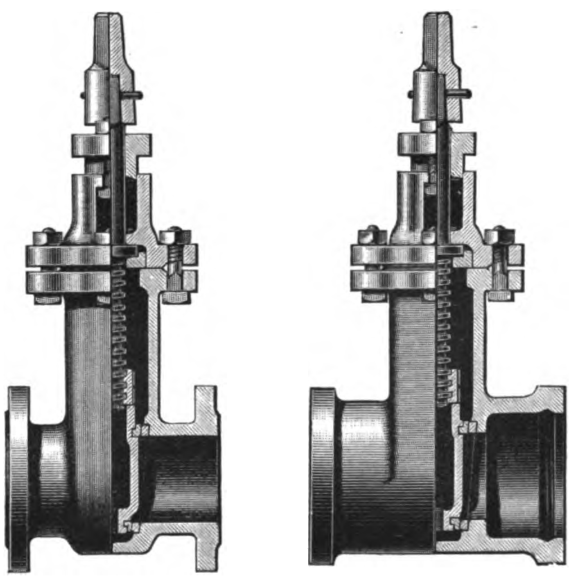

FIG. 57.—Socketed and Flanged Sluice Valves.

flanged sluice valve. The spindle, the gate or disc, and the facings or seatings are of phosphor bronze.

Where changes of direction occur, bends constructed to a large radius must be used, and all junctions must be of the double-curved pattern shown in Fig. 58, so that the friction due to change of direction will be minimised.

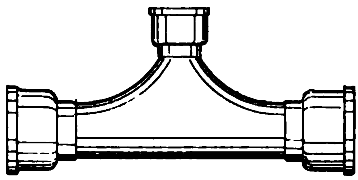

Fig. 58.—Circular Junction.

Air Valves are necessary to automatically release the air which becomes disengaged from the water and accumulates in the highest parts of the mains. They also serve to facilitate emptying and refilling of the mains, by allowing a free passage for air in either direction.

Double-action air valves are frequently used with a central valve for shutting off the water in case of repairs.

The spheres are of vulcanite, and are loaded so as to float. They are therefore forced against the seatings when the air is expelled and water enters the body of the valve.

In certain districts the variable character of the contour of the ground renders it necessary to adopt measures to reduce

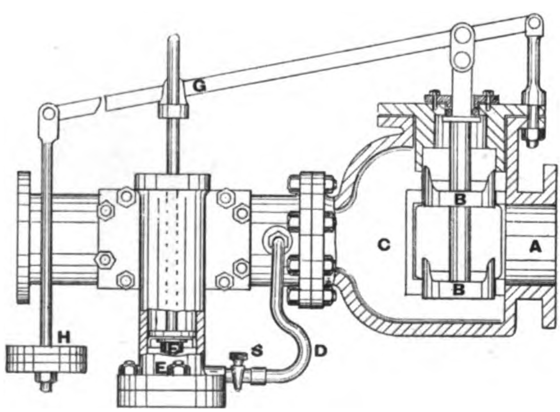

Fig. 59.—Pressure-reducing Valve.

the pressure in the mains of the lower sections, owing to the abnormal stresses to which the conduits and fittings would otherwise be subjected, and the consequent heavy wear and

tear upon the same, and to prevent the greater leakage which would result from defects.

Fig. 59 shows a *pressure-reducing valve* of the weighted type. The water enters at A, lifts the double valve B, and escapes into the outlet C; the small pipe D communicates with the cylinder E, and the pressure of the water tends to lift the piston F, thus raising the weighted lever G and closing the valve B. The thrust required for the latter purpose will be governed by the number of weights on the platform H. Thus, if the pressure at A is 250 lbs. per sq. in., and it is required to reduce this to 100 lbs. per sq. in. at C, weights are added to or removed from H until the pressure of 100 lbs. per sq. in. communicated through D to the piston F will raise the lever G and close the valve. If it be required to equalise the pressures in A and C, the cock S is closed, and a free passage through B is thus obtained.

Fire Hydrants are fixed on the service mains at distances of from 50 to 200 yards apart, according to the character and closeness of the buildings. They are of two principal kinds, viz., "the ball hydrant" and "the valve hydrant." The former, which is shown *in situ* in Fig. 60, consists of a vulcanite ball that is forced by the water-pressure against a seating. In case of fire a stand-pipe having a central spindle is attached to the projecting lugs, and by rotating a handle the ball is forced downwards by the descending spindle.

The chief disadvantage of this fitting is the liability of pollution of the water by insuction during emptying of the mains previous to repairs. The hydrant box is the recipient of road-washings, a portion of which enters the pipes when the system is emptied.

Fig. 61 shows the valve hydrant, in which the water supply to the stand-pipe is controlled by a screw-down valve forming a permanent part of the fitting.

There is practically no risk of pollution occurring with the use of this type, unless the valve be turned on whilst the mains are being emptied.

The detection of waste of water and prevention of the same is a matter of great importance to waterworks authorities. The enormous cost and difficulty of securing a pure supply to a community make it essential that, as far as the limits of

practical economy will allow, every gallon shall be delivered to the consumer.

When it is considered that in a scheme of distribution of

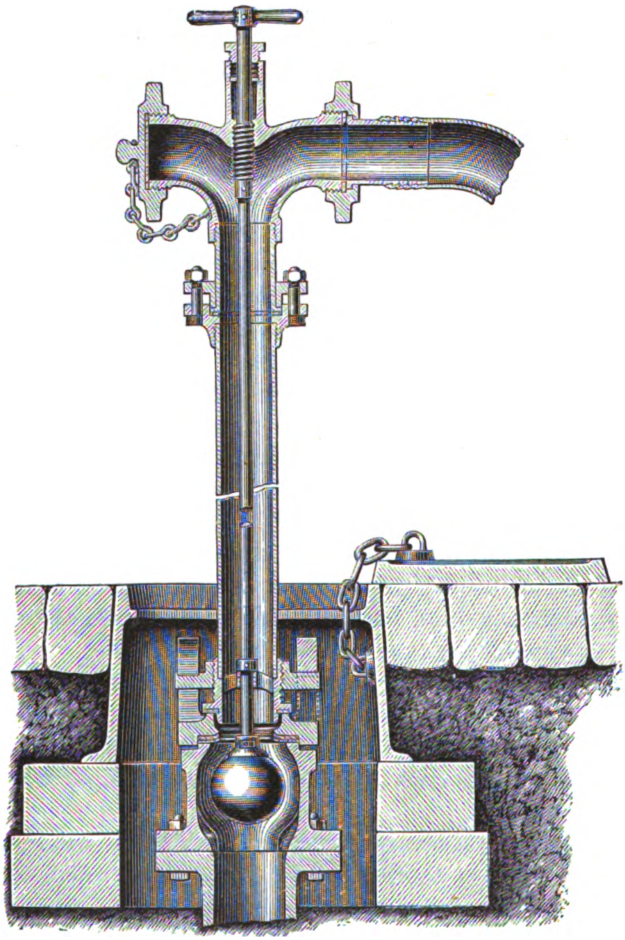

Fig. 60.—Ball Hydrant *in situ*, with Stand-pipe attached.

moderate size there are many miles of pipes of various diameters, and thousands of joints and fittings laid and fixed under conditions that are often inimical to a perpetual condition of staunchness, the necessity for close and continuous control

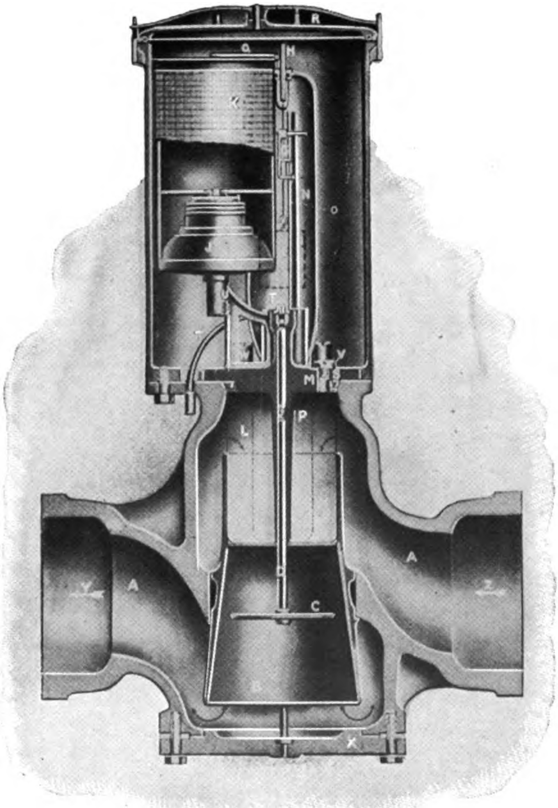

Fig. 62.—Palatine Water-waste Detecting Meter.

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and inspection to detect, locate, and remedy defects is obvious if economical results be desired.

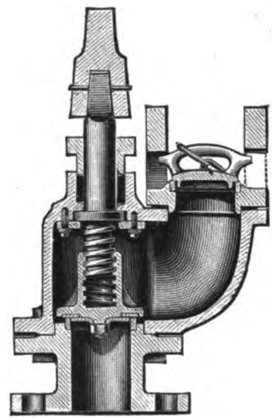

FIG. 61.—Valve Hydrant.

Intelligent waterworks inspectors aided by efficient apparatus can by a systematic inspection localise defects.

The Palatine Water-waste Detecting Meter was designed some years ago by the late George Deacon, Esq., an eminent waterworks engineer. It can be attached to existing systems, and by a detachable device one meter can be made to serve several districts.

Fig. 62 shows a sectional elevation of the meter. It consists of a cast-iron body, A, containing the gauge cone B, in which the disc C works. The stem D is connected by a hard brass wire to the pencil-carrier G, which in turn is kept in position by the weight E (shown in dotted lines): the flexible wire passing over the pulley H connecting the weight with the pencil-carrier. The clock J causes the drum K to rotate once in twenty-four hours, or once in seven days, according to the adjustment of certain toothed wheels. The working parts are enclosed by the airtight cover R, which can be quickly detached.

Action of the Meter.—When a flow of water takes place through the meter the disc is forced down and forms a waterway between the disc and cone; the area of the annular space thus formed is proportional to the amount of water passing.

As the flow of water increases the disc descends, and *vice versâ*, and for any given flow the disc will maintain one position in relation to the gauge cone.

As the pencil G is connected to the disc C, its movements are recorded on the graduated diagram, which is fixed on the drum K.

The paper diagram is marked off by vertical lines representing time in hours, and horizontal lines indicating in gallons the amount of water that the meter will pass when the recording pencil is at any given point on the diagram.

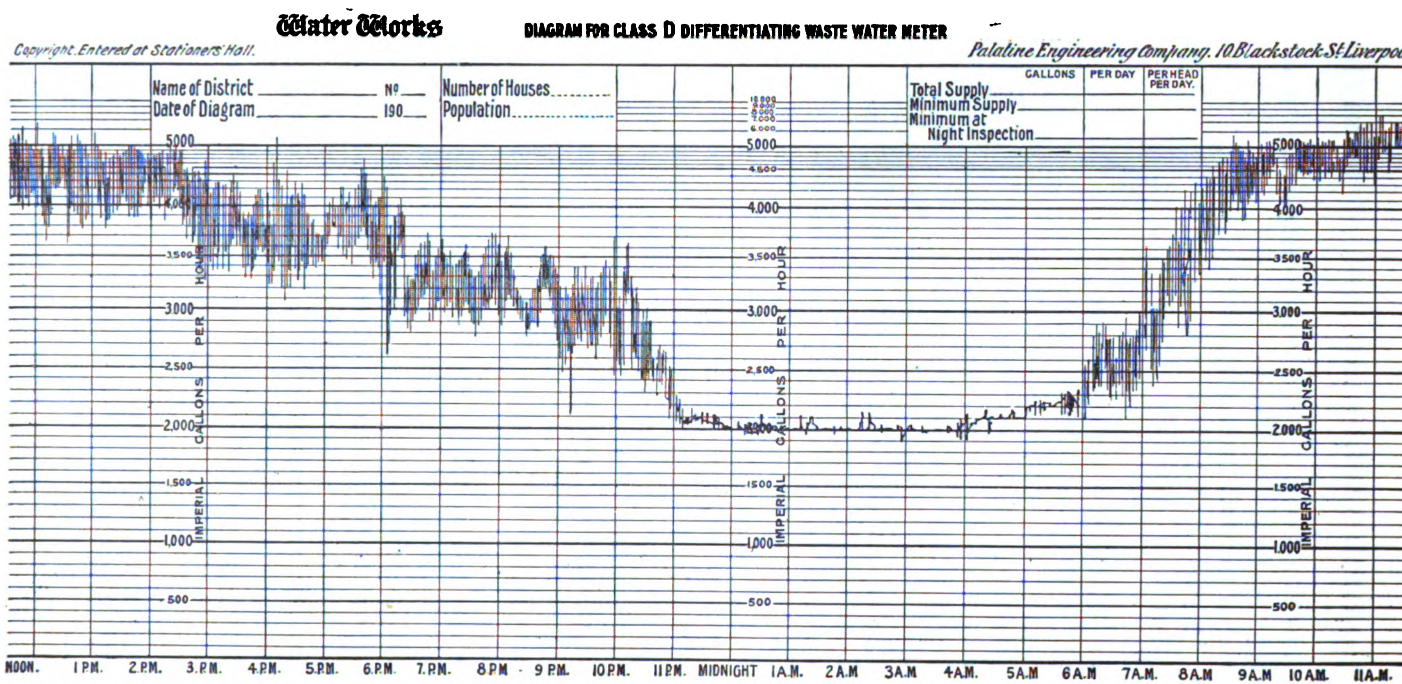

Fig. 63.—Diagram of Twenty-four Hours' Flow through Waste-water Detecting Meter.

The amount of water consumed in any district varies considerably during the daytime, and it is not possible to utilise the day record for detecting waste, but between the hours of 12 P.M. and 5 A.M. the consumption is practically *nil*, therefore the indicator pencil would record a fairly straight mark on the zero line of the diagram if the pipes and fittings are staunch, and no water is drawn for mill boilers or for similar purposes. Should there be leakages, the quantity passing through the meter will be indicated by the depression of the disc, which will move the pencil to a mark on the diagram corresponding to the volume going to waste per hour.

Fig. 63 shows a diagram of a twenty-four hours' flow. The leakage in this example amounts to approximately 2000 gallons per hour, as indicated by the pencil mark between midnight and 5 A.M.

The application of this method of waste detection by meter is shown in Fig. 64.

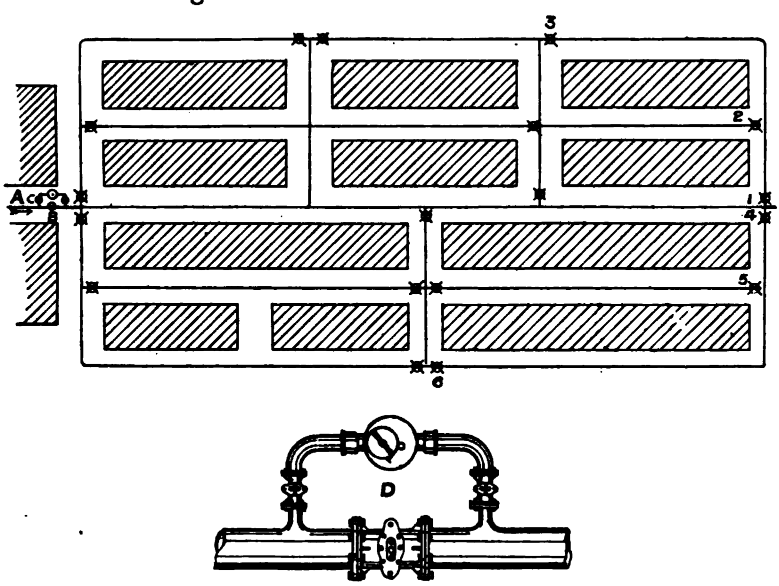

FIG. 64.—Diagram of Mains, showing Application of Waste-detecting Meter.

The principal main, A, is provided with a sluice valve at B, and a by-pass C, in the centre of which the meter is fixed as

shown by the enlarged detail, D. The service mains are controlled in sections by numerous sluice valves.

If a waste of water is suspected, a diagram is affixed to the drum of the meter, and the flow of water diverted through the by-pass by closing the valve B and opening the two valves C C. A record is thus obtained of a twenty-four hours' consecutive flow. If an abnormal consumption be recorded, a new diagram is placed on the drum, and a night test and inspection made. The inspector closes the valves of the section of service mains most remote from the meter, as 1, 2, 3, and at the end of one hour examines the diagram. If the pencil mark is identical with that on the previous diagram, no leakage is apparent in that section. Section 4, 5, 6 is next treated, when a reduction of consumption after another one hour's observation determines a leakage in this section. The process is repeated until the whole of the sections have been systematically shut down, or until the pencil returns to the zero line, thus proving that the remaining sections are staunch.

Fig. 65. Stethoscope.

Accurate records are made during the observations. The work of detection and localisation of leakages is greatly facilitated by using a stethoscope, which conveys the sound emitted by running water to a discharge disc. The relative loudness of the sounds heard are a reliable guide as to the nearness of the defect to the point of observation.

Fig. 65 shows one form of stethoscope consisting of a bamboo rod, having a metal ferrule at its lower end and a discharging disc on its upper end. The lower end is placed in contact with a valve or pipe, and in some cases with the surface of the ground. It is during the stillness of the night only that the use of the stethoscope in the latter position is practicable.

Service Pipes are conduits which convey the water from the mains in the road to the buildings. They may be of lead, wrought-iron, cast-iron, or copper.

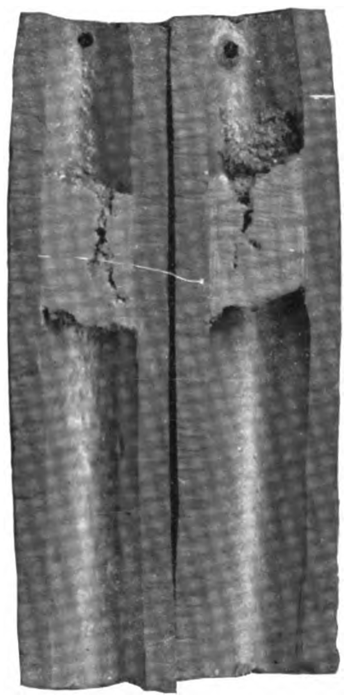

Fig. 66.—Defective Tinned Lead Pipe.

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Lead Pipe is most generally used on account of its great adaptability, low cost, the long lengths in which it may be obtained and laid (thus necessitating fewer joints), and its resistance to corrosion. In certain waters a plumbo solvency is present, which makes the use of lead pipe a source of danger to the water consumers. The various methods that have been devised for treating the interior of lead pipes are enumerated in Part I., pp. 22, 23; none of these methods are eminently satisfactory. Where plumbo-solvent waters are to be carried, "Walker's Health Pipe" gives satisfactory results.

The "tin-washed" lead pipe is worse than useless, for a galvanic action is set up which intensifies the solvent action of the water; moreover, there is a liability of the bore of the pipe becoming choked by a mixture of lead and tin during pressing operations. Fig. 66 shows a photograph of two halves of a $\frac{3}{4}$-in. tin-washed lead pipe which was submitted to the writer. It was taken from the service pipe laid to supply a building with water. Considerable difficulty and expense were entailed before the defect was located.

An analysis of the metallic plug revealed the fact that its composition was 11·64 per cent. lead and 88·36 per cent. tin, thus showing that it had taken up a quantity of lead during the tinning process.

Various jointing processes are in use; but so far the one which is the most reliable, and which is generally adopted, is the plumbers' wiped joint.

There has just been introduced a substance known as "amalgaline," by the aid of which lead pipes can be quickly jointed. The two pipe ends are prepared by paring the interior of one and the exterior of the other by means of a special tool until they fit each other accurately. A strip of "amalgaline" of extreme thinness is wound round the prepared spigot end, which is then forced into the socketed end; the flame from a Swedish torch is brought to bear on the parts, and the "amalgaline" melts and joins the pipe ends together. The "amalgaline" consists of tin-foil coated with a mixture of stearin and vaseline, which acts as a flux.

The thickness of a lead pipe is denoted by the weight of a lineal yard of the same.

All waterworks authorities issue a list of the weights

of lead pipes to be used for services within their areas of supply.

The following table contains the sizes and weights of lead pipe per lineal yard, as required by some of the principal waterworks authorities in this country.

Towns.

Sizes.	Manchester.	Glasgow.	Dublin.	London.	Aberdeen.	Newcastle.	Stockport.
In.	Lbs. per lineal yd.	Lbs. per lineal yd.	Lbs. per lineal yd.	Lbs. per lineal yd.	Lbs. per lineal yd.	Lbs. per lineal yd.	Lbs. per lineal yd.
$\frac{3}{8}$	5	...	5	5	...	...	5
$\frac{1}{2}$	6	7	6	6	7	7	7
$\frac{5}{8}$	$7\frac{1}{2}$	...	$7\frac{1}{2}$	$7\frac{1}{2}$	9	9	...
$\frac{3}{4}$	9	11	9	9	11	11	11
1	12	16	12	12	14	16	16
$1\frac{1}{4}$	16	$22\frac{1}{2}$	16	16	18	$22\frac{1}{2}$	22
$1\frac{1}{2}$	21	30	...	21	24	...	28

Wrought-Iron Service Pipes are frequently adopted in districts supplied with hard water. If they are galvanised, their life is considerably lengthened, as they are not so readily corroded by contact with moisture. When they are laid in earth, the exposed portions of the screwed ends should be covered with a double coating of white lead paint, to protect the iron.

The strengths of wrought-iron pipe are denoted by the terms "gas," "water," and "steam," the strengths of the two latter being nearly equal. They are made in lengths of from 10 to 16 ft.

The "water" strength should always be used, and the pipe should be obtained from reliable makers, to ensure a clear bore and freedom from flaws.

The "screwed" joint is invariably adopted, and a luting of red and white lead or graphite and oil applied to the threads before they are screwed together.

Elbows should be avoided, and either stock bends or purpose-made bends used.

The weights and sizes of wrought-iron water-pipe per foot-run are given in the following table:—

Sizes, Gauges, and Weights of Wrought-iron Tubes.

Nominal Bore in Inches.	Approximate Outside Diameter in Inches.	Threads per Inch.	Gas.			Water.			Steam.		
			W.G.	Weight in lbs. per foot.		W.G.	Weight in lbs. per foot.		W.G.	Weight in lbs. per foot.	
				Black.	Galvanised.		Black.	Galvanised.		Black.	Galvanised.
1/8	13/32	28	14	·27	·302	13	...	...	12	·32	·352
1/4	17/32	19	14	·40	·448	13	·438	·47	12	·486	·495
3/8	11/16	19	13	·56	·627	12	·62	·69	11	·68	·748
1/2	27/32	14	12	·84	·924	11	·92	1·003	10	1·01	1·091
3/4	1 1/16	14	11	1·20	1·32	10	1·32	1·44	9	1·43	1·544
1	1 11/32	11	10	1·67	1·804	9	1·82	1·95	8	2·01	2·136
1 1/4	1 11/16	11	9	2·34	2·475	8	2·58	2·722	7	2·80	2·94
1 1/2	1 29/32	11	8	3·10	3·255	7	3·37	3·522	6	3·76	3·911
1 3/4	2 5/32	11	8	3·642	3·787	7	4·05	4·192	6	4·356	4·486
2	2 3/8	11	7	4·21	4·379	6	4·67	4·834	5	5·07	5·222
2 1/4	2 5/8	11	7	4·602	4·786	6	4·98	5·154	5	5·475	5·639
2 1/2	3	11	7	5·334	5·547	6	5·775	5 977	5	6·318	6·507
2 3/4	3 1/4	11	7	5·842	6·076	6	6·325	6·546	5	6·921	7·129
3	3 1/2	11	7	6·326	6·579	6	6·851	7·091	5	7·499	7·724
3 1/2	4	11	7	7·162	7·448	6	7·759	8·031	5	8·5	8·755
4	4 3/8	11	7	8·051	8·373	6	8·723	9·028	5	9·555	9·842
4	4 1/2	11	7	8·282	...	6	8·975	...	5	9·833	...
4 1/2	5	11	7	9·083	9·446	6	9·839	10·183	5	10·776	11·099
5	5 1/2	11	7	10·17	10·577	6	11·009	11·394	5	12·051	12·413
5 1/2	6	11	7	11·494	11·954	6	12·438	12·873	5	13·61	14·018
6	6 1/2	11	7	12·573	13·076	6	13·601	14·077	5	14·878	15·324

The "Health" water-pipe, described on pp. 35, 36, Part I., has been extensively used during recent years. Great care is required in cutting, screwing, and otherwise preparing the joints. Special sockets are provided, with a hole in the centre, so that any escape past the leather washer will be indicated on the outside of the pipe.

Where the pipes are to be laid underground, they should be placed in troughs of rough wood and surrounded with a bituminous compound to prevent contact between the earth and the pipe, otherwise a rapid decay of the pipe is probable.

Copper service pipes, owing to their high cost, are not often used. They should be heavily tinned inside and out with pure tin.

The joints that are adopted vary in different localities. The left- and right-hand screwed joint, and the ordinary right-hand screwed joint are commonly used, either with

tinned and sweated threads, or with the addition of a luting of graphite.

The thickness of copper pipe is indicated by the Imperial Wire Gauge standard, and also indirectly by the weight per lineal foot.

Most waterworks authorities require the copper tube to be of steam strength, but this is unreasonable, as such pipes will withstand enormous pressures and are not corroded so readily as pipes of wrought-iron would be if placed under similar conditions.

The laying of service pipes should receive special attention. On no account should they be laid through ashes, vegetable refuse, or filled-up ground without some precaution being taken to prevent the acids that are generated in such materials from corroding the pipes.

An envelope of clay 6 ins. thick will give good results, but where possible the pipe should be laid in a wooden trough and surrounded with a mixture of dried sand and coal-tar, or bitumen.

The depth of the pipe below ground-level should be not less than 3 ft. To secure immunity from the action of frost during severe winters, a depth of 4 ft. is needed.

The connection of the service pipe to the main is now usually accomplished without shutting off the water in the mains.

Fig. 67 shows a view and section of Donnelly's under-pressure main-tapping apparatus. The machine consists of a fluid-tight cast-iron body containing a spindle to which a combined drill and tap is attached by a left-hand screwed cap. The top of the drill is slotted, with the object of maintaining a rigid connection during drilling and tapping operations.

A stopcock ferrule and a drill are placed in position, and the machine is then clamped to the main by a strong chain. When the main is drilled and tapped, the spindle S is withdrawn until the mark M is level with the top of the packing gland G. The drill will then be above the line L, and the projections on the slotted cap C engage with the recesses R in the brass sleeve. The latter is pivoted to A at P. A partial turn of the spindle to the right brings the ferrule carrier below and concentric with the sleeve.

The ferrule is thus brought directly under the drill and

above the tapped opening. The spindle is lowered gently and the drill enters an adapter or cap which is screwed to the top

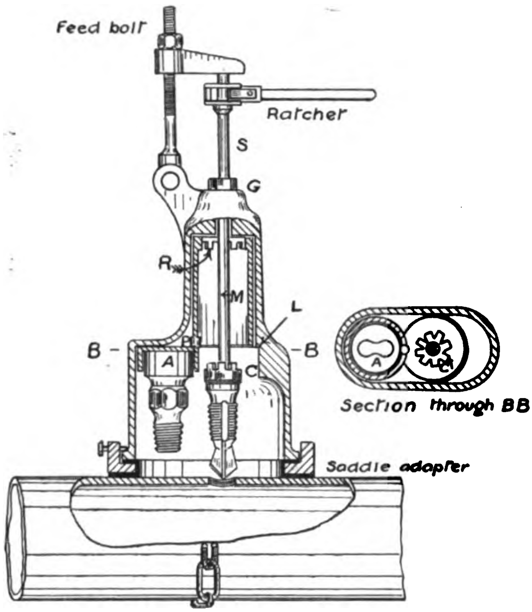


Fig. 67.—Donnelly's Under-pressure Main-tapping Apparatus.

of the ferrule. The spindle is rotated with a slight downward pressure, and the ferrule is screwed into the main.

Fig. 68 shows a view and part section of the ferrule. The

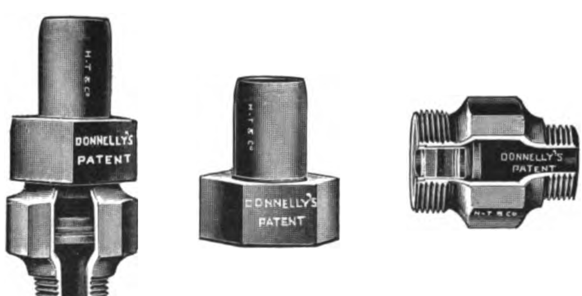


Fig. 68.—Ferrules for Under-pressure Main-tapping Apparatus.

cap and lining are removed, and the adapter attached before placing the ferrule in the carrier of the machine.

The valve is of brass or gunmetal ground on the seating to form a watertight joint. The pressure of the water in the main keeps the valve closed until the cap and lining are attached. The long pap on the latter forces back the valve during the screwing-up process. A full waterway is obtained automatically, which obviates the risk which obtains with certain types of ferrules, of inadvertently leaving the water shut off and filling in the excavation.

Gas connections can be inserted by the use of this machine

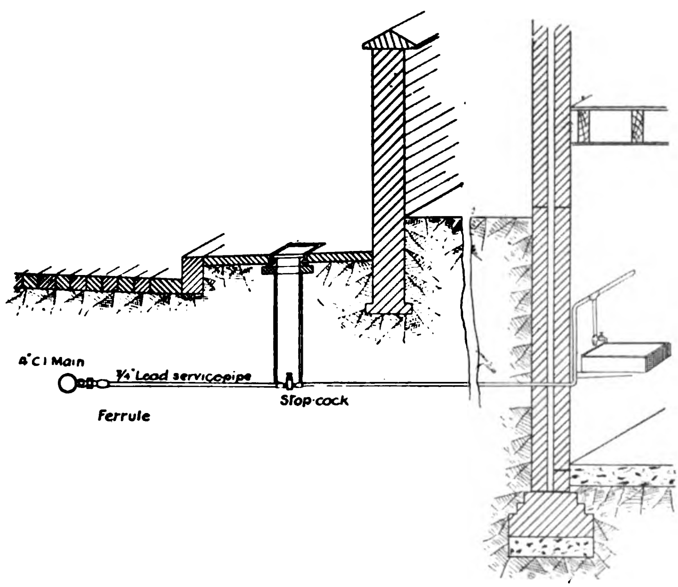


Fig. 69.—Service Pipe from Main to House.

without loss of gas. A modified type of ferrule is used which costs very little more than an ordinary ferrule.

The machine is simple in construction and very effective, and has given highly satisfactory results where adopted.

By the use of the "under-pressure" drilling and tapping machines, loss of water and inconvenience to consumers, and the risk of pollution due to emptying of water-mains that are fractured or are fitted with ball hydrants, are avoided.

Stopcocks are generally provided on that portion of the service pipe laid under the footpath, and access boxes are

necessary to allow the water inspector to control the supply to the building without entering the same.

Fig. 69 shows a section through such an arrangement. An additional stopcock should be provided on the pipe inside the building, so as to control the supply from within. This is a convenient arrangement, especially in winter-time, when bursts are liable to occur.

Constant and Intermittent systems of water supply.— The arrangement of the pipes inside the building will be influenced by the method of supply in vogue in any particular district.

The term "constant" is applied to undertakings in which the distribution mains are kept fully charged with water under sufficient pressure to ensure at all times a delivery of water to the highest building within the area of supply.

"Intermittent" systems are those in which the water is turned on in the distribution mains for a portion only of each day. The length of time during which the water is turned on varies in different districts, but is usually from half an hour to four hours. In the intervals between the supply periods, the water for domestic use is obtained from storage tanks fixed in the high parts of the buildings.

The "constant" system is adopted where possible on account of the obvious advantage which it possesses over the intermittent system.

The reason for the adoption of the latter system is to be discovered in the limited character of the water supply, and the existence of an old system of distribution mains which possibly is defective.

Storage tanks restrict the quantity supplied to each building, and thereby prevent undue consumption of water.

The following are the advantages of the "constant" system:—

1st. There is no necessity for storage of drinking-water on the premises.

2nd. The domestic supplies are drawn as required from the town's main, and the water is well aerated and more palatable than water stored in an open tank on the premises.

3rd. In case of an outbreak of fire, the water is usually available

in ample volume, and also under sufficient pressure to raise it to a requisite height.

4th. The cost of the internal arrangements of pipes, etc., is less than in the "intermittent" system.

5th. There is less risk of pollution by insuction during distribution.

The disadvantages are:—

1st. In cases where the mains, service pipes, and fittings are old and defective, the loss of water is greater.

2nd. During repairs and alterations in connection with the distribution mains, the sanitary fittings are without water.

The advantages of the "intermittent" system are the disadvantages of the "constant" system.

The disadvantages of the intermittent system are:—

1st. Cost of providing additional pipes and a storage tank.

2nd. The flat, insipid taste of stored water and the risks of pollution during storage.

3rd. The probabilities of pollution whilst the water is in the distribution mains.

This occurs usually during emptying of the mains; the earth in a semi-liquid state surrounding a defect is drawn into the pipe by reason of the partial vacuum that is formed, owing to the escape of water at lower levels.

4th. In case of fire it may be necessary to turn on the water in certain sections of the mains, during the period when the maximum demand is made by the houses within the particular section of supply, thereby resulting in a much reduced delivery at the hydrants.

5th. The alternate contact of air and water with the interior of the pipes tends to accelerate any rusting action which may be started, thereby shortening the life of the pipes.

Fig. 70 shows an arrangement of the pipes in a house supplied on the "constant" principle.

The following points must be observed when arranging the pipe routes, etc.:—

1. Size of service pipe. This should be such as will meet the maximum demand during periods when the pressure in the mains is at a minimum.

For houses supplied on the "constant" principle, pipes varying from ½ in. to 1 in. will be sufficient, but where a large number of fittings derive their cold

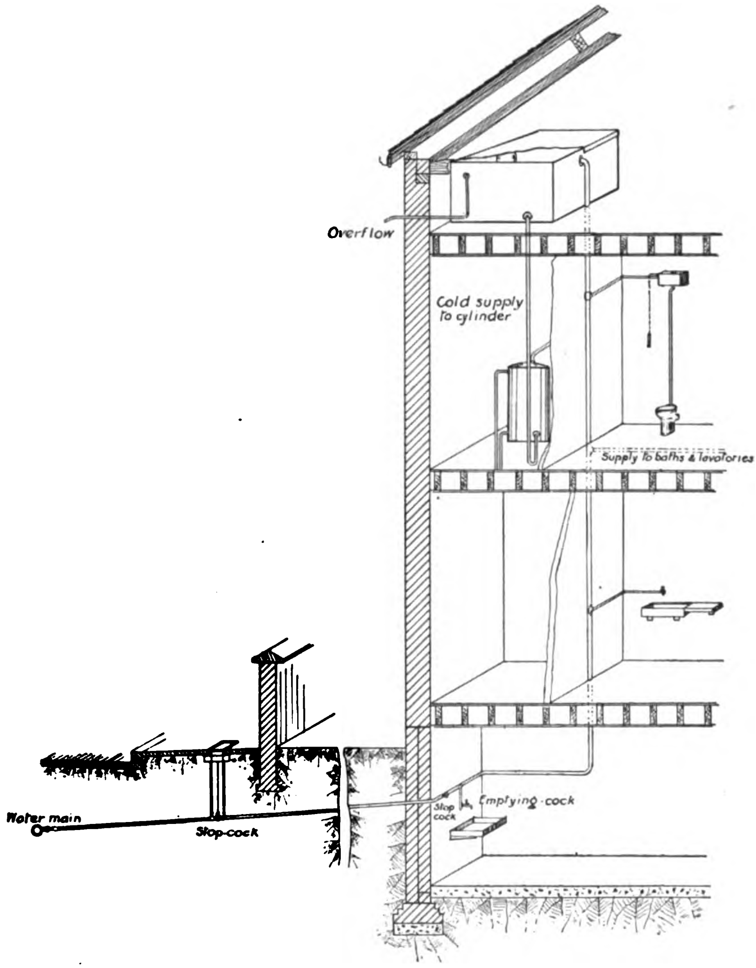


Fig. 70.—House fitted with Pipes for a Constant Water Supply.

supplies direct from the service pipe, the diameter may require to be increased to 1½ ins. It is always advisable to have adequate provision as regards the sizes of service pipes; the small additional cost of using the size above the normal one is money well spent.

In the case of "intermittent" supplies, larger service pipes are necessary, the minimum size being ¾ in.

The sizes of pipes for branches to fittings do not follow any definite rule. They are dependent largely upon the pressure in the mains and the "main room"—*i.e.* the discharging capacity of the mains.

In many cases a ½-in. pipe will prove sufficient for a bath; whereas in other instances a pipe 1 in. diameter will deliver a smaller quantity in the same time, owing to the smallness of the head or the insufficiency of the mains.

2. The provision of stopcocks inside and outside the premises.
3. The pipes must be inclined towards the lowest point, where provision must be made for emptying them. Such an arrangement will be of service during repairs, or when there is risk of the water being frozen.
4. Outside walls and other exposed positions should, if possible, be avoided when arranging the pipe routes, and all pipes fixed in positions where frost will have access should be protected by a good non-conductor of heat carefully applied.
5. Wooden grounds must be provided for pipes fixed vertically.

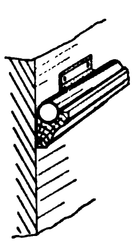


Fig. 71.—Method of fixing Pipes.

Pipes must not be buried in plaster.

Pipe hooks are not to be used for supporting lead pipes under any circumstances. They are unsightly, and are liable to cause damage to the pipe.

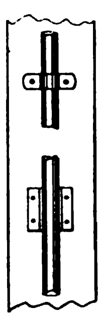


Fig. 72.—Method of fixing Pipes.

Brass or galvanised iron clips should be used with pipes in vertical positions. They may be fixed from 2 to 3 ft. apart. Lead lugs soldered to the pipes can be used as substitutes with advantage. The clips and lugs must be screwed to the wooden supports, as shown in Fig. 71.

For wrought-iron and copper pipes, the supports need not be so frequent as in the case of lead.

For horizontal or inclined positions, wooden fillets must be used, as shown in Fig. 72.

6. All joints on lead pipes shall be of the plumber's wiped type.
7. Connections of the service pipe with sanitary fittings shall be arranged in such a manner that there will be no risk of pollution of the water.

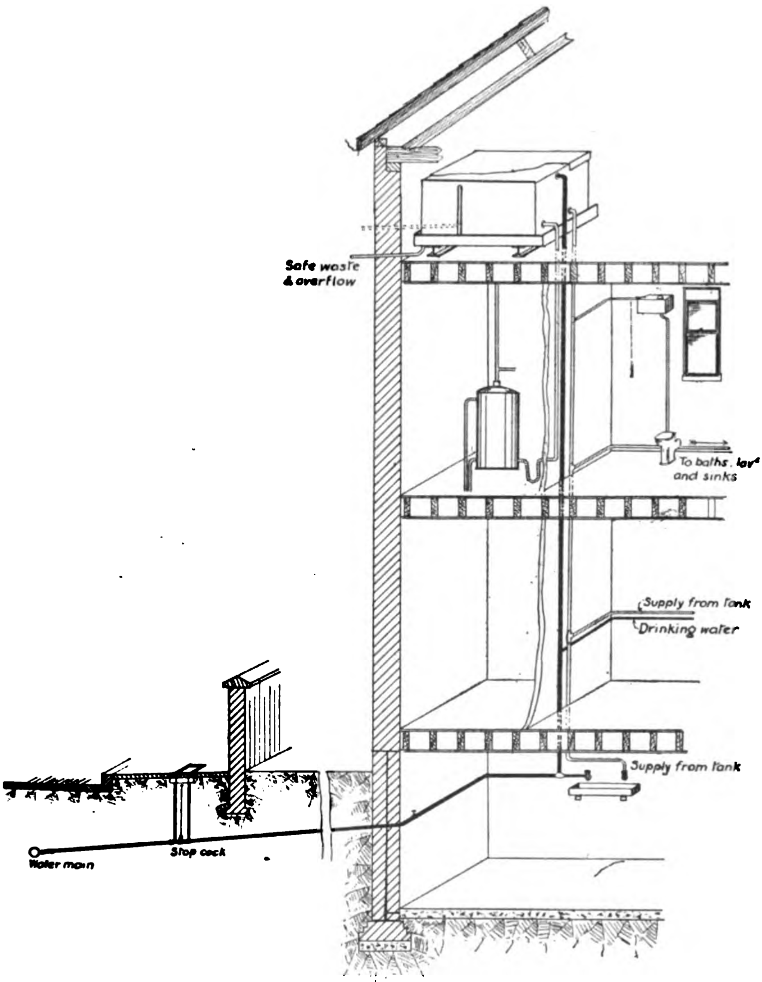


Fig. 73.—House fitted with Pipes for an Intermittent Supply.

Supplies to slop sinks, water-closets, and urinals shall be disconnected from the fittings by means of a suitable flushing tank.

The pipe arrangements in the "intermittent" system are shown in Fig. 73. The service pipe is shown in bold lines, and the tank supplies to the fittings are indicated by finer double lines.

It will be observed that drinking-water and all other domestic water is drawn from the storage tank. The former can, however, be obtained direct from the service pipe at the tap over the sink, but only whilst the water is turned on in the mains.

The size of the service and distribution pipes requires careful consideration in this system. The former should have twice the cross-sectional area of that required under the same circumstances for a "constant" system, and the sizes of the latter pipes should be so regulated as to give a requisite supply to each fitting during periods of the greatest demand.

Full-way stopcocks should be provided on the supplies from the tank so as to impose a minimum amount of obstruction to the flow of water.

Table of Non-conductors (Felt being taken as Unit, i.e. 1·00).

Useful for covering Steam, Hot- and Cold-water Pipes.

Substance.	Relative Value.	Remarks.
Loose Wool	3·35	Very Good
Feathers	1·10	,,
Felt	1·00	,,
Charcoal (cork)	·87	,,
Silicate cotton (slag wool) . .	·85	,,
Straw rope (loose) . . .	·75	Very Fair
Cork	·71	,,
Sawdust	·68	,,
Wood	·50	,,
Asbestos	·50	,,
Sand	·17	Poor
Stone	·02	Bad

Storage Tanks are necessary in all buildings possessing modern systems of domestic hot-water services, and in all cases where the intermittent system of supply is in vogue.

The following materials are used for the manufacture of storage tanks:—Wood, tinned and plain sheet-copper, sheet lead, zinc, galvanised sheet-iron, cast-iron (painted, glass-

lined, or coated with Angus Smith's composition), glazed stoneware, and slate slabs. Copper, lead, and zinc require wooden enclosures for their support. The remainder do not require any additional support.

Lead, zinc, plain copper, and galvanised iron are not suitable materials for storing pure, well-aerated, or slightly acid water, or water containing chlorides and nitrates. These waters act upon and dissolve such metals, and, in the case of lead, will give rise to plumbism in the systems of certain consumers who are predisposed to lead-poisoning.

Heavily tinned copper can be used with advantage, or cast-iron (glass-enamelled), glazed stoneware, or slate may be adopted.

In the case of water containing two or more grains of lime, carbonate or sulphate per gallon, any one of the materials first mentioned may be used.

Galvanised Wrought-Iron is the cheapest material. It is very serviceable, and is therefore commonly used under such circumstances.

Glazed Stoneware Tanks of large capacity cannot be obtained owing to the practical difficulties experienced in the drying and burning processes of their manufacture. If made in slabs and bolted together, they have no advantage over slate, excepting in appearance. Where their use is desirable, several tanks can be connected together by means of pipes of large diameter to obtain the requisite storage capacity.

Slate Storage Tanks are formed of slabs bolted together. The bottom and two sides of each tank are grooved to admit of a ⅜-in. housing of the joining edges. The sides project several inches past the ends, and these portions are holed to receive the clamping bolts. The joints are usually made by filling each groove with a stiff paste of red and white lead before housing the joining surfaces; where this material is adopted, the exposed seams inside the tank should be covered with an angular fillet of Portland cement to prevent pollution of the water, which would otherwise result from contact with the lead compounds.

Portland cement is occasionally made to take the place of the red lead, but it is liable to disturbance from vibration.

Narrow strips of stout calico thickly coated with natural

bitumen will give good results. The strips should be of the same width as the grooves.

Wood Storage Tanks are not suitable owing to the risk of fungi developing on their inner surfaces and the possibility of decay of the fibres.

Cast-Iron Storage Tanks are eminently suited to meet the requirements of large buildings. They may be obtained in stock sizes from various makers, and are usually built up of flanged plates bolted together. The flanges are machined, and jointed with thin strands of oakum, or strips of mill board. In some cases a groove is formed inside which is filled with Portland cement or rust cement. The iron must be protected by either painting the surface or having each plate treated with Angus Smith's composition. The latter is preferable to the former.

Position and Fixing of Storage Tanks.—In all cases they should be fully accessible for periodic inspection and cleansing. The apartments in which they are fixed should be well lighted and adequately ventilated, and should not be used as bedrooms or living-rooms.

A dust-proof cover of unpainted wood should be placed over each tank. In the case of large tanks a lead safe will be necessary to prevent damage to the rooms below by leakage from the joints or fittings of the tank.

The overflow, which must be of sufficient capacity to take the maximum discharge from the ball tap, should be fixed at a point below the level of the ball tap, and its outer end must be provided with a dust-proof hinged flap. It should discharge in a prominent position away from any drain opening.

The "safe" waste pipe must be similarly treated.

Under certain conditions it may be advantageous to terminate the overflow pipe above the "safe" waste pipe, as both these act primarily as warning pipes.

The "draw-off" pipes should enter the side of the tank at a point 2 ins. above the bottom, so that any sediment which accumulates will not pass from the tank to the fittings.

Fig. 74 shows a section through a slate storage tank, *in situ*. A detail of the joints of the slate slabs is given in Fig. 75.

In the case of lead-lined wooden tanks the same details obtain as regards supply, overflow, draw-off, and safe waste pipe.

The "stand-pipe overflow" is often used in connection with large tanks, and in country districts where the rain-water is stored direct from the roofs. It facilitates the emptying and cleaning operations that are necessary about four times per year.

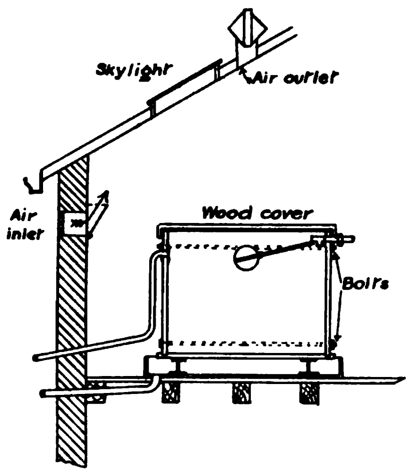


Fig. 74.—Section through Slate Tank with Lead-lined Safe.

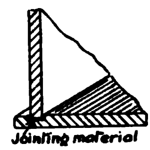


Fig. 75.—Section through Joint for Slate Tank.

Fig. 76 shows a section through a stand-pipe overflow, *in situ.* The tank is of wood, lead-lined, the angles being joined by wiped fillets of plumber's solder.

When shaving the lead previous to soldering, care should be taken to entirely remove the lead oxide, and the cleaned surface should be smeared instantly with tallow. The heated solder should be splashed on to the seam and its immediate vicinity, and a clean plumbing-iron, heated to redness, should be used in all wiping operations.

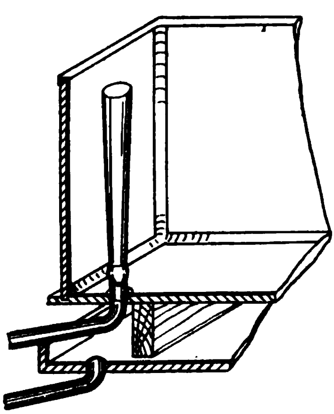


Fig. 76.—Lead-lined Wooden Tank with Overflow and Safe.

The Cylinder Storage Apparatus is a decided improvement on the open tank method. Fig. 77 shows this arrangement.

The cylinder is of ¼-in. wrought-iron galvanised plates riveted together. It is fixed in an accessible position in a high part of the house.

The water enters through the service pipe, and, when the tank is full, the float valve B closes over the air pipe and overflow pipe C. The service pipe acts as the supply pipe to the fittings.

When the water is turned on in the mains the house supplies are served from this source, but during the period that the water is turned off, the content of the cylinder is drawn upon. The reflux valve D prevents the water from passing back again into the mains.

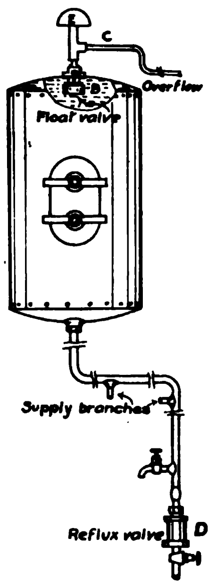


Fig. 77.—Cylinder Method of Water Storage.

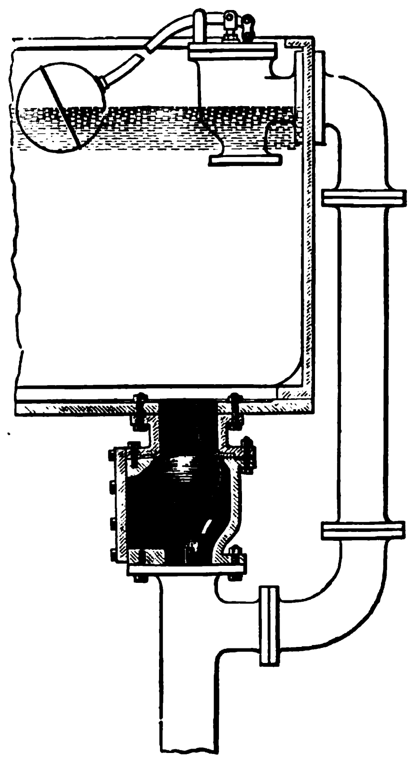


Fig. 78.—By-pass Connection between Tank and Service Pipe.

The air strainer E is filled with cotton wool, asbestos, or slag wool. The air passes through this filtering medium during the emptying of the cylinder. This device tends to prevent contamination of the stored water.

In large buildings, public offices, schools, etc., where the demand upon the water supply is excessive at certain intervals during each day, it may be advisable to arrange for storage accommodation to tide over such periods.

This can be accomplished at a small increase of cost, by adopting an arrangement similar to that shown in Fig. 78.

A by-pass service ensures the automatic charging of the tank through the ball valve, the spherical check valve beneath the tank meanwhile being closed, but when the pressure of the water in the tank is greater than that in the town's main the valve opens and ensures a full supply to the establishment.

A reflux valve is necessary at the foot of the rising main to prevent the tank content from passing into the mains.

Water Meters.—Water for domestic purposes is generally charged for on the basis of the rental of the house, with additional fixed charges for services to extra sanitary fittings (over a certain number), and for garden and photographic purposes.

Water required for trade purposes, and that supplied to hotels and public buildings generally, is invariably sold "by meter," at a fixed price per 1000 galls.

Appliances used for measuring water are of two principal types:—

1st. Positive meters.

2nd. Inferential meters.

A Positive Meter contains an arrangement which measures the water, and records the amount passed through the appliance in a given time.

The measuring device usually adopted is of the cylinder and piston type, and meters which embody this principle are usually reliable.

An "Inferential Meter" measures the volume flowing through it by inference, based upon the effect of the kinetic energy exerted on the blades or buckets of a fan wheel, which is connected by geared mechanism to the recording dial.

There is less restriction placed upon the flow by this type of meter as compared with the positive type, but it will not accurately record small deliveries.

Fig. 79 shows a section through the Kennedy positive meter.

The measuring cylinder is of cast-iron, brass lined, and all the moving parts are of gunmetal or phosphor bronze. The piston rod is provided with a rack and pinion *motion*, which communicates the effect of each up and down stroke to a small counter shaft possessing a left- and right-hand ratchet motion.

The alternate up and down strokes of the piston are thereby converted into a continuous circular motion, which is transferred by geared mechanism to the recording dial.

The water enters the meter through the cock key, which diverts it through the conduit D to the under side of the piston. On completion of the upstroke, the tumbling lever is

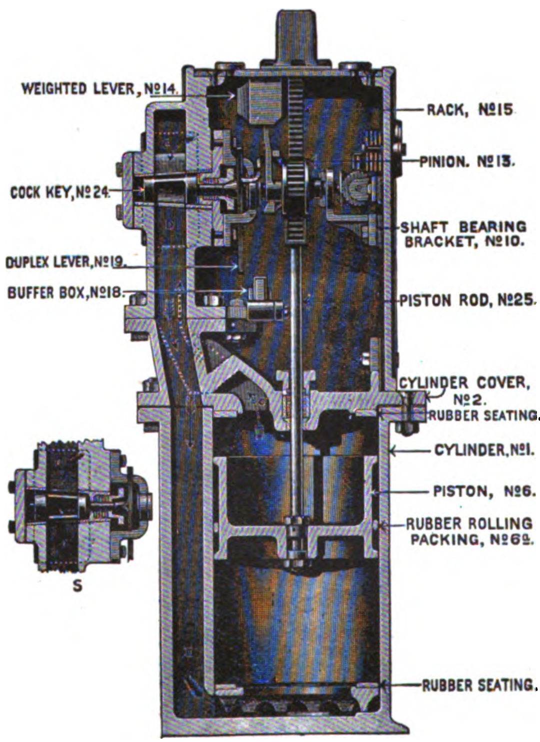


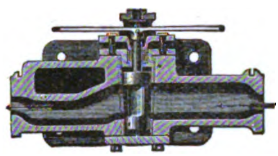
Fig. 79.—Kennedy "Positive" Meter.

thrown over by a projecting arm attached to the pinion, and, falling on the duplex or rectangular lever attached to the cock key, it gives this a quarter of a full turn, which directs the water into the conduit C, communicating with the top of the piston.

Fig. 80 shows an arrangement of the conduits. The position of the cock key in the sketch is causing the water to enter the cylinder beneath the piston; but when the change occurs at the

termination of the stroke, the water from A passes through C on to the top of the piston, and the water from beneath is forced into the outlet B. Conversely, when the downstroke occurs the water on the top of the piston is forced through C into B, as shown in sketch.

This meter is used in all the principal towns in the United



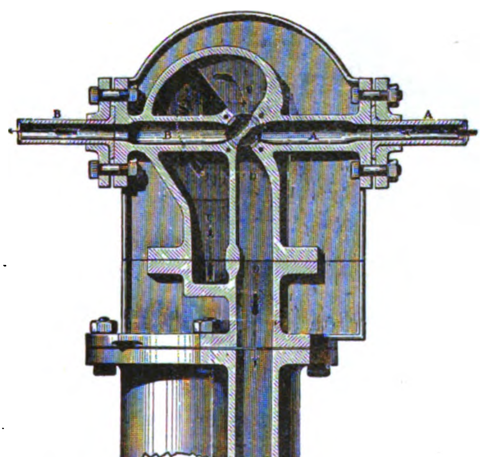


FIG. 80.—Construction of "Positive" Meter.

Kingdom, and is said to give accurate results under any condition of supply.

There is not a great loss of "head" during the flow of the water through the meter, owing to the friction of the piston rod being minimised by using a rolling packing of best Para rubber.

This type of meter is obtainable in sizes suitable for pipes of from $\frac{1}{2}$ in. to 8 ins. diameter. There are other excellent forms of positive meters, but lack of space prevents their inclusion.

The amount delivered per hour by a meter is largely influenced by the head of water and the length of pipe through which the water passes before and after leaving the meter.

Fig. 81 shows a vertical section of Tylor's inferential meter. The water enters the fan case through guide slots, which direct it on to the blades of the fan wheel so that the line of force is tangential to the periphery of the fan. The water rises into the upper part of the chamber or fan-wheel case, and passes into the outlet through apertures or ports.

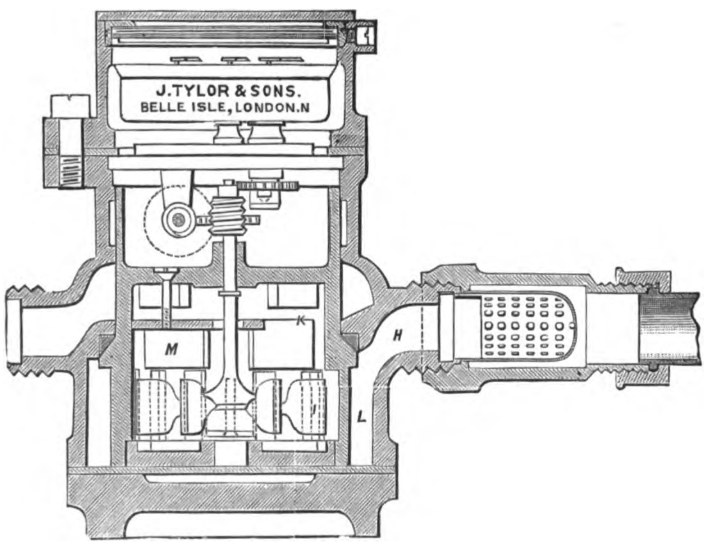


Fig. 81.—Tylor's "Inferential" Meter.

To ensure greater accuracy in recording variable flows, vortex chambers are formed at intervals in the circumference of the fan-wheel case, and vertical surfaces are constructed which deflect a portion of the escaping water on to the revolving blades. These agencies have a retarding effect upon any erratic tendency in the motion of the wheel.

The motion thus produced is transferred by means of a worm gear to the recording mechanism.

Inferential meters give fairly accurate records where the flow is constant and the volume passed is considerable; but in cases of slight leakages from valves and defective pipes, they do not give reliable readings of the leakages.

These meters are suitable for works purposes where large quantities of water are used daily.

The recording apparatus invariably consists of one or more dials, grouped in various ways. The principle of the indicator is the same in each case.

Fig. 82 shows the dial of the recording apparatus of the Kennedy meter. No. 5 is the shaft attached to the pinion

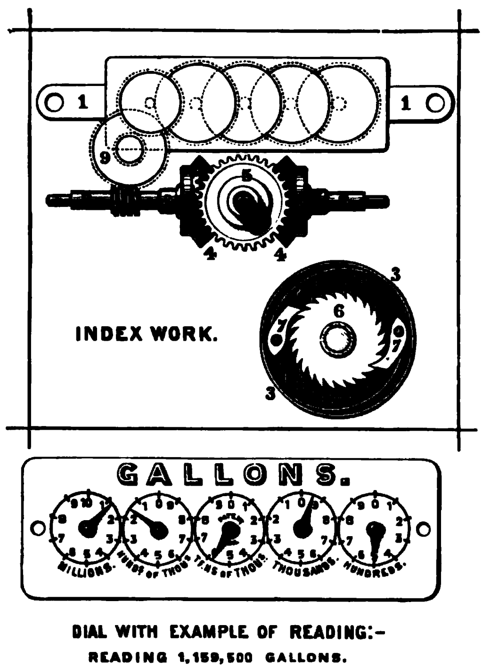


Fig. 82.—Meter Recording Dials.

which operates the left- and right-hand ratchet motions 4, 4. The worm on shaft No. 2 operates the toothed wheel No. 9, which in turn transfers the motion to the graduated toothed wheels to which the index fingers are attached.

The reading shown in the example is 1,159,500 gallons.

The amount of water to be stored in the tanks fixed in premises where the intermittent principle of supply obtains, is generally based upon one day's storage, allowing from 15 to 25 gallons per head.

Various estimates are obtainable as to the disposition of the amount stored.

Willoughby gives the following probable division of 25 gallons per head:—

	Galls.
Domestic use, such as washing, cooking, etc.	12
Water-closets	6
Baths	4
Waste	3
	25

Water Fittings are made of brass, gunmetal, and phosphor bronze.

Yellow brass containing zinc is not suitable for use with acid water, as the zinc is quickly corroded, leaving rough seatings, which result in leakage and ultimately the cost of renewal.

Gunmetal containing 80 per cent. copper, 15 per cent. tin, 5 per cent. lead, is suitable for soft and acid waters.

Phosphor bronze is used principally in the movable parts of valves, especially where the wear and tear and the stresses to which they are subjected are abnormal. This alloy is very tough, and will resist both a wearing action and a high tensile stress.

The strength of the fittings is generally proved to a certain point before despatching them from the works.

Waterworks authorities invariably require that all fittings connected either directly or indirectly with their service pipes shall have sustained a pressure of not less than 300 lbs. per square inch without fracture or permanent distortion.

The terms "valves" and "cocks" are now used in a general sense to apply to the various devices that are in vogue for controlling the flow of water through pipes. Strictly speaking, a "cock" consists of a conical-shaped brass or gunmetal plug, fitted into a "body" of the same metal, through which a passage is provided; the plug is pierced, so that when adjusted in one position a straight throughway is obtained, but when given a turn of 90°, the intact sides of the plug are brought across the waterway and entirely block it. They are frequently spoken of as plugcocks.

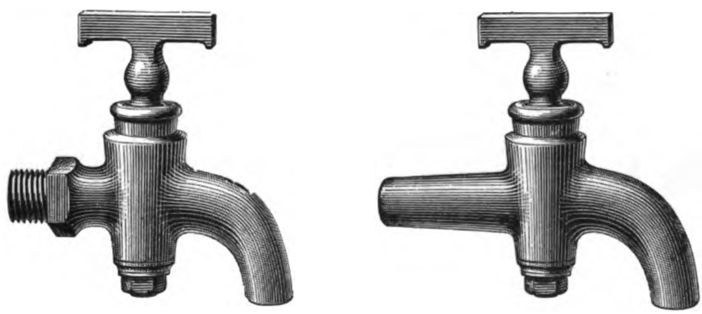
A valve achieves the same object by use of a screw or lever

motion, which forces a movable valve against a seating, and thus effectively blocks the aperture.

Valves and cocks may be treated under the following headings:—

(1) Plugcocks.
(2) Valve taps.
(3) Self-closing taps.
(4) Ball taps.

Fig. 83, A and B, shows two types of bibcocks, one of which is provided for attachment to a lead pipe, whilst the other is screwed to accommodate a wrought-iron service pipe; or for connecting with a screwed elbow boss.



A B

FIG. 83, A and B.—Two Types of Bibcocks.

The term "bib" cock or valve implies that water may be drawn through such fittings.

Fig. 84 shows different types of stopcocks for fixing on service pipes to control the supplies to houses or to individual fittings or groups of fittings.

The use of plugcocks is attended by the following disadvantages:—

1*st*. The ground surfaces upon which tha watertightness of the cock depends are quickly scored and grooved if fine sand is present in the water, thus causing continual loss of water and oft-repeated repairs.

2*nd*. The tendency to sudden closing of the waterway, owing to the quick action of the plug, is liable to cause "water-hammer," which is frequently responsible for fractured pipes.

3*rd*. When used on hot-water services, the plug and body

may expand and contract under slightly different coefficients, and thereby cause permanent distortion and subsequent leakage.

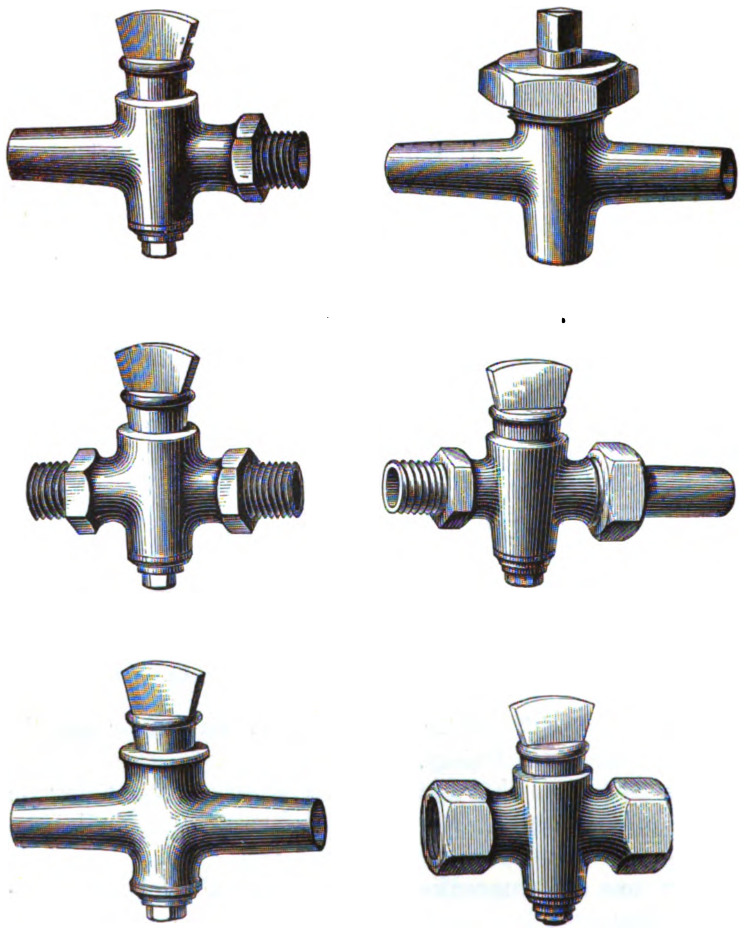


Fig. 84.—Stopcocks of various patterns.

Valve Taps for water services are of two forms: bib taps and stop taps.

Fig. 85 shows a section through a valve bib tap. The valve is provided with a leather washer for cold water. A hard rubber or a fibre washer is used with hot water.

In hard water districts the seating upon which the valve rests

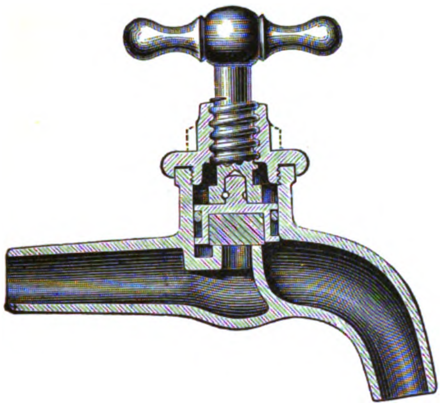


FIG. 85.—Bib Tap.

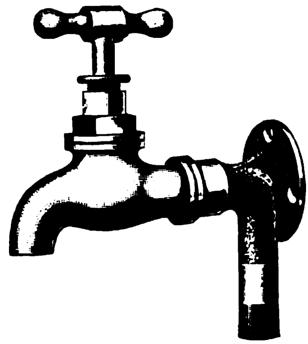


FIG. 86.—Tap attached to Elbow Boss.

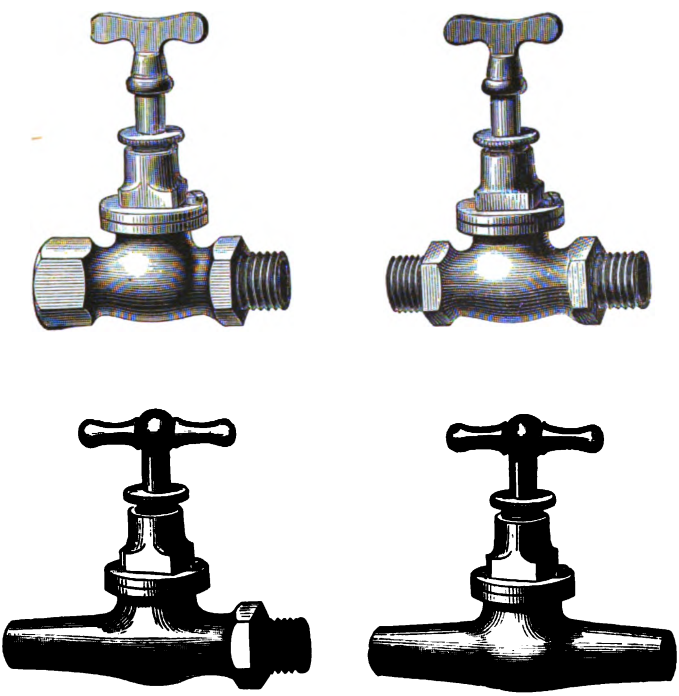


FIG. 87.—Valve Stop Taps.

becomes serrated by deposits and rapidly destroys the washer. The taps may be reseated with the aid of a special appliance.

For hot- and cold-water services over sinks, lavatories, and baths, the taps must be "indexed."

Fig. 86 shows a method of connecting a bib tap with an iron or a lead pipe. This arrangement is more satisfactory than that involving a soldered joint between the tap and a lead pipe. It has a neater appearance, can be more firmly fixed, and the tap may be renewed without difficulty.

Fig. 87 shows several forms of valve stop taps of the screw-down pattern, adapted for connection to lead, wrought-iron, or copper pipes.

Kelvin Taps are based on the principles laid down by the late Lord Kelvin, a scientist of great eminence. The essential feature of each tap is the peculiar structure of the valve, which is brought to rest on its seat by a concentric gliding motion that tends to resurface the valve and seating at each closing of the tap, whilst the relative surfaces are maintained strictly parallel by the elastic force of a strong spring of phosphor bronze that exerts a thrust on the outer edge of the upper surface of the valve.

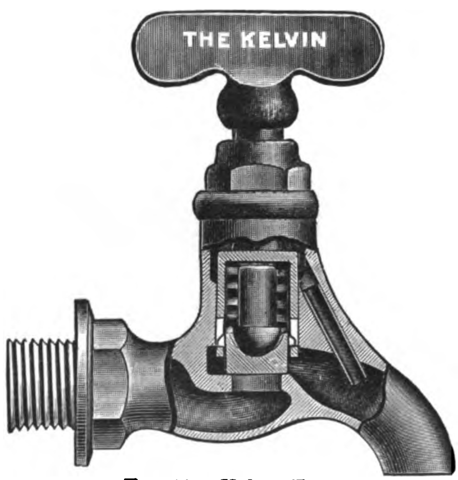


Fig. 88.—Kelvin Tap.

Fig. 88 shows a part section of a "Kelvin" bib tap.

The valve, which is of gunmetal or of vulcanite, is brought to rest gradually by the aid of the spring. The turning of the spindle causes the valve to rotate on the seat before it is brought to rest by the rivet stop. The stuffing-box is dispensed with, and the water which enters the spindle chamber is drawn into the outlet through the eduction tube.

The principle is applied to bath and lavatory taps and to

stop taps, but in the latter the eduction tube is dispensed with, and an ordinary stuffing-box substituted.

Fig. 89 shows the Kelvin bath and lavatory taps respectively.

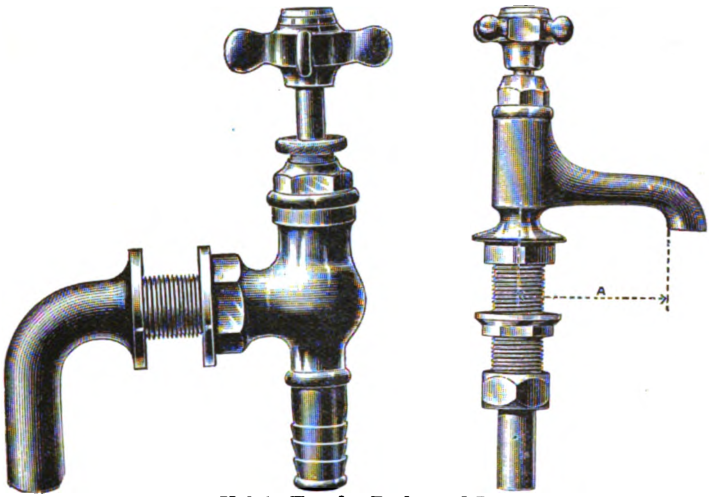
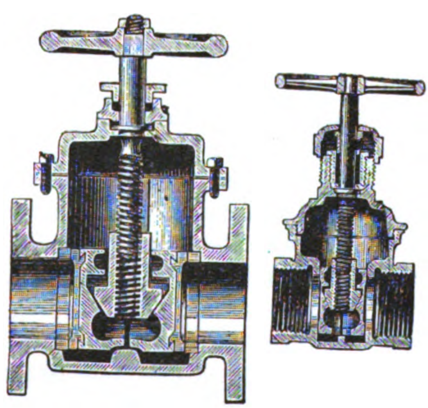


Fig. 89.—Kelvin Tap for Baths and Lavatories.

Full-way Stop Taps are very useful on hot- and cold-water services, especially where the pressures are low. The obstruction caused by the passage of the water through the tortuous windings in an ordinary screw - down stop tap greatly reduces the velocity.



A B

Fig. 90, A and B.—Peet's Valve.

Fig. 90, A and B, shows "Peet's" full-way valves. In each case the spindle is made of phosphor bronze, and its lower end screws into the wedge-shaped socket, which forces the two gunmetal discs against the ground surfaces in the body of the valve. This fitting can be obtained with either screwed or flanged ends for wrought-iron pipe work, or tinned ends for use with lead pipe.

Several devices are applied to the bib tap fitting for the purpose of obviating the shutting off of the water supply to a house when the washer of the tap requires renewing. Certain of these are embodied in the design of the taps, whilst others are contained in the elbow bosses to which the taps are secured.

Fig. 91 shows a part section and view of a simple arrangement, whereby the screwing of the tap in the socket of the boss forces backwards a gunmetal cylinder, and admits water to the tap through the ports provided in the cylinder. The dotted lines show the position occupied by the cylinder when

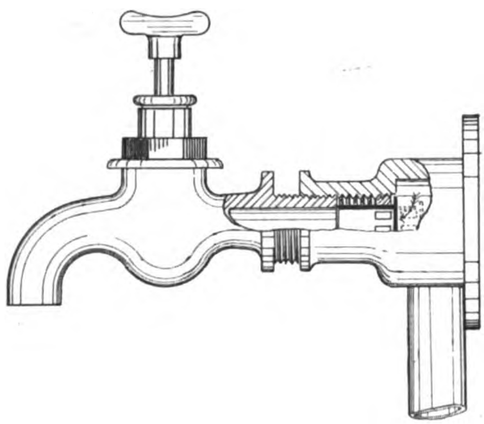


FIG. 91.—Bib Tap with Stop Valve.

the tap is screwed fully into the boss, and the full lines show its position previous to the insertion of the tap.

Where fittings are used by irresponsible persons, **self-closing taps** are necessary to obviate the waste of water which would occur if taps of the ordinary type were fixed. There are many forms of this fitting, but few of them are satisfactory. The mechanism essential to the working of some of these taps is too complicated, and is easily dislocated; other taps of simpler construction set up violent concussion, due to the quick-closing action which they develop.

Fig. 92 shows a section through a non-concussive self-closing tap. On pressing the spindle downwards, a small valve is first opened, which allows the water to escape from the spring chamber through the hollow rod into the tap outlet.

The pressure on the lower surface of the valve is thus reduced, and the main valve is forced downwards by the pressure of the water.

When the spindle is released, the water slowly fills the lower chamber and exerts an upward thrust on the valve

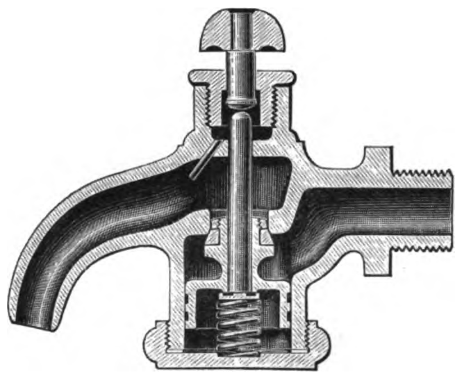


Fig. 92.—Self-closing Bib Tap.

sufficient to close it. The spring simply carries the weight of the valve, and assists in overcoming friction during the closing action.

Frost Taps contain a device whereby the service pipes may be automatically emptied when the tap is turned off. Fig. 93 shows a view of a plugcock. The lower part of the plug has a small port at right angles to the main port.

When the water is turned on, this occupies the position shown by the circle A, but when turned off, the water in pipe B may pass through the by-pass C, and escape at D.

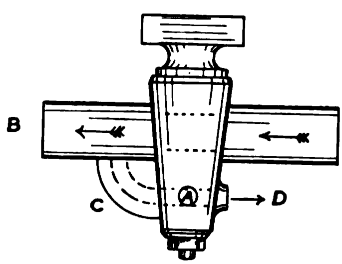


Fig. 93.—Stopcock with By-pass.

Ball Taps are appliances used for the automatic control of the supply of water to tanks or cisterns. They are of three principal types:—

1*st*. Low-pressure ball taps.
2*nd*. High-pressure ball taps.
3*rd*. Quick delivery ball taps.

Low-pressure ball taps are usually of the direct-action type, as shown by Fig. 94. The valve is provided with a rubber washer, and is closed by the upward thrust of the water in the tank acting on the copper ball. The force giving the lever an arc-like motion is caused to act horizontally against the valve by means of the cam on the short end of the lever.

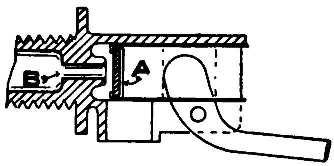


Fig. 94.—Low-pressure Ball Tap.

The chief fault of this form of ball tap is its small bore, which greatly restricts the delivery of water, especially under low pressures.

Fig. 95 shows Brazier's ball tap, which has a slightly larger

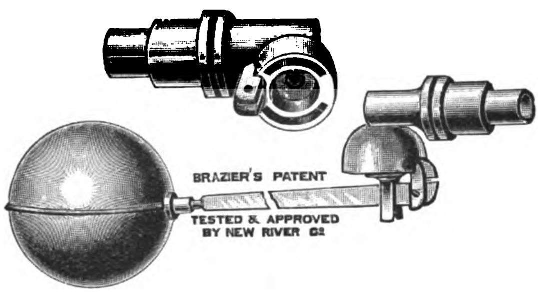


Fig. 95.—Brazier's Ball Tap.

waterway than the example shown in Fig. 94; also, it embodies the second order of levers. The closing arrangement acts with a minimum of friction.

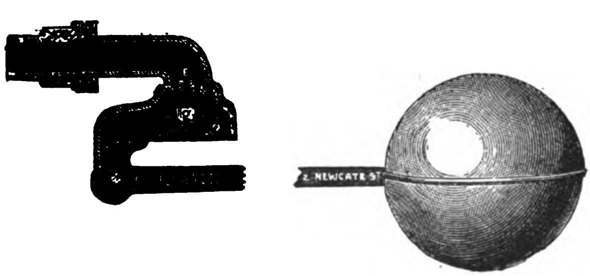


Fig. 96.—Tylor's Cam-action Tap.

Low-pressure types of ball taps should not be used for pressures exceeding 80 lbs. per square inch. Under the influ-

ence of high pressures these taps close with difficulty, and give rise to unpleasant humming noises. They are often responsible for occasional or continued discharges of water through the overflow pipes of the cisterns or tanks. The lever may have power sufficient to close the valve against the static pressure, but the kinetic energy developed in the water flowing through the orifice may be of such moment as to bring about a condition approaching equilibrium of the two opposing forces acting on the opposite surfaces of the valve. This causes an oscillation or throbbing of the valve, accompanied by unpleasant noises.

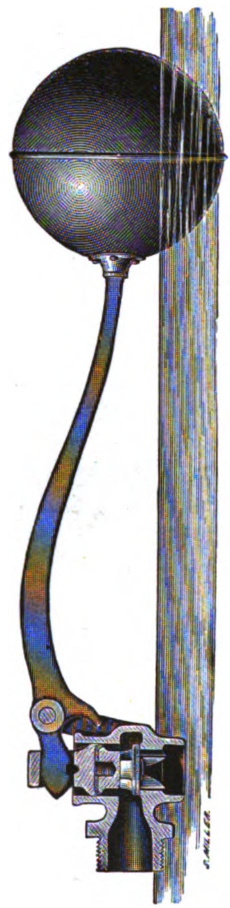


FIG. 97.—High-pressure Ball Tap.

High-pressure ball taps are of two principal types. One consists of an arrangement of compound levers which multiply the thrust of the water on the copper ball.

Fig. 96 shows a section through Tylor's cam-action ball tap. This fitting has a comparatively large waterway, and is suitable alike for high and low pressures.

Fig. 97 shows the second type of high-pressure ball tap, which is known also as an equilibrium ball valve. The force tending to open the valve is neutralised by the thrust of the water against the upper disc, thus the valve is kept closed by a very small force acting through the lever. When the tap is delivering water the lever is easily able to overcome the difference between the kinetic force acting on the lower disc and the static force acting on the upper disc, and thus close the valve. The chief defect of this valve is the cup leather, which is liable to get out of order and give rise to leakage.

Ball taps may be obtained with or without union attach-

ments prepared for connection to lead or wrought-iron pipes.

Where the service pipe to a tank is two or more inches in diameter, a "quick-delivery balanced ball valve" may be used

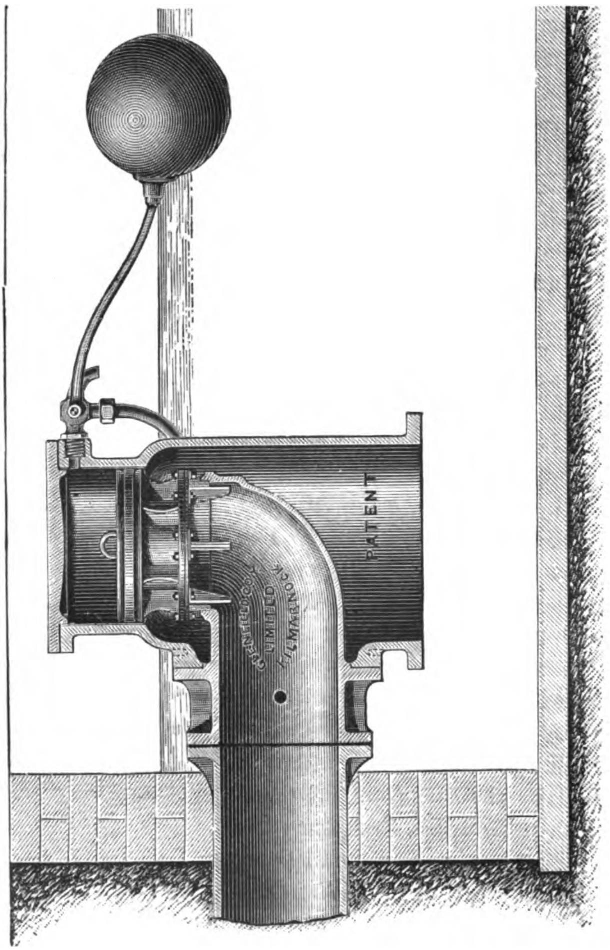


Fig. 98.—Equilibrium Ball Tap.

with advantage. This fitting gives a full-bore delivery, closes with comparative slowness when the tank is full, and occupies only a small space.

Fig. 98 shows a section through such a valve. It consists of a double-faced piston, of which the upper face works in a

brass-lined cylinder, and the lower one, provided with a rubber washer, rests on a brass seat. A small-bore pipe conducts a supply of water to the top of the piston; when the small ball tap opens, this supply is not sufficient to overcome the thrust below the valve seat, and in consequence the valve is raised.

When the tank is filled, the closing of the ball tap causes the pressure to accumulate in the piston chamber and closes the valve.

It will be observed that the upper face of the piston has a larger area than the lower face.

A Silencing Pipe is used to reduce the noise caused by the water entering a cistern. It consists of a piece of lead or copper tube attached to the outlet of the tap, and continued to the bottom of the tank.

A hole $\frac{1}{8}$ in. in diameter should be pierced in the upper part of the pipe to prevent the content of the tank being siphoned back again into the service pipe, when the water is turned off and the pipes are being emptied, whilst the cistern is only partly filled.

Water-Hammer is the term applied to the shock due to the sudden stoppage of a train of water in an enclosed conduit.

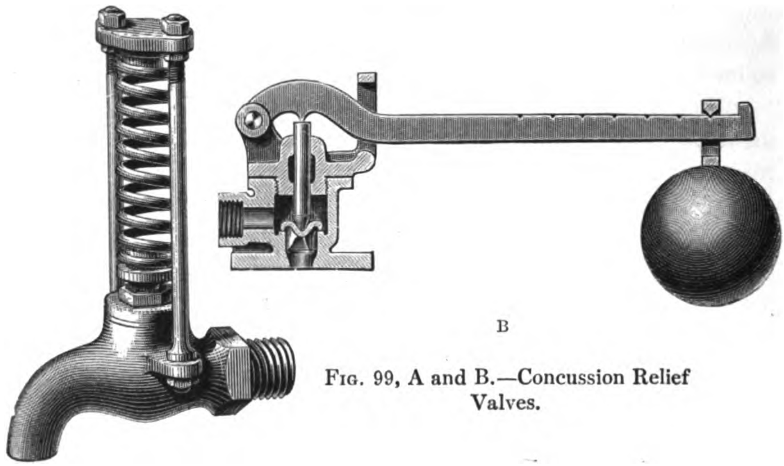
This does not often occur in the cast-iron mains laid under the roads and streets, as the valves used are of the slow-closing type; but in buildings where quick-closing valves are used, whether in connection with hydraulic machinery or domestic services, there is some risk of water-hammer occurring.

It is more liable to take place in long lengths of pipes than in short lengths, especially if there be any sharp bends to negotiate. Under certain conditions of delivery, the pressure at a bend may be less than that of the atmosphere, and the sudden stoppage of the delivery will then result in the production of shock, which may be sufficient to fracture the bend if it be weaker than other portions of the pipe.

Two methods are adopted for the relief of concussion. The first consists of a relief valve constructed after the pattern of a safety valve, to open at a given pressure and thus considerably reduce the shock.

The valve may be of the dead-weight, lever, or spring type. These appliances are used principally on the larger sizes of pipes.

Fig. 99, A, shows the spring type of relief valve, and B shows a section through the lever type.



A

B

Fig. 99, A and B.—Concussion Relief Valves.

The second method consists of the provision of an air-cushion, which absorbs the concussive force or shock, and reacts but slowly, thereby avoiding damage to the pipes.

Where possible, slow-closing valves only should be used, but where such fittings cannot be adopted, air-vessels of sufficient capacity, judiciously fixed, will give satisfactory results.

An air-vessel should be fixed as near as possible to the fitting responsible for the shock. For pipes of $\frac{1}{2}$ in. to 1 in. diameter, from 2 to 3 ft. of 2-in. light copper tube will form a neat air-vessel.

Arrangements must be made for re-charging the air-vessel periodically, as the air will be gradually absorbed by the water under pressure.

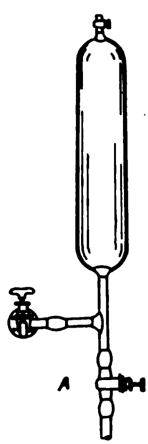


Fig. 100.—Air-vessel on Service Pipe.

Fig. 100 shows an air-vessel attached to the end of a service pipe, supplying a tap with water.

The vessel is of copper, and the small cock is provided for the periodic admission of air, which, with the aid of the stop tap A, may be carried out each day.

WATERWORKS REGULATIONS

Regulations are enacted by all waterworks authorities for the guidance and control of those who provide and fix the pipes and fittings necessary for supplying water to dwellings and other buildings.

The revised and up-to-date regulations of the Manchester Corporation Waterworks are given in the following pages (by the kind permission of the chairman and members of the Waterworks Committee):—

NOTE.—For convenience the following terms are used :—

(*a*) "Communication pipe" includes the pipe laid by the Corporation from the main to the premises;

(*b*) "Service pipe" includes all pipes laid by the consumer which are under pressure from the mains;

(*c*) "Distributing pipe" includes all pipes from cisterns or tanks which are supplied with water by the Corporation.

APPLICATIONS FOR WATER

1. Persons requiring a supply of water must obtain from the authorised officer of the Waterworks Committee instructions as to the proper point for the introduction of the water on to the premises. Such persons must, at their own cost, provide, lay down, and maintain all pipes and fittings which may be required within their premises; also lay one foot of service pipe beyond the boundary thereof to enable the connection to be made with the main. (In the case of meter supplies, see Reg. No. 17.)

APPLICATION FORMS

2. Printed forms will, upon application, be supplied to plumbers, which they must fill up and deliver at the Waterworks Office, Town Hall, as a notice of the fittings being ready for inspection, both as regards new property and alterations and additions to fittings in old property.

APPROVAL OF FITTINGS

3. All pipes, cisterns, taps, valves, and other water fittings, and all arrangements of the same, are subject to the approval of the Waterworks Committee, and must comply with their regulations. Unless specially exempted, all taps, valves, and water-closet and urinal cisterns must, before being fixed, bear the stamp M.C.W.W. Exception in regard to stamping is made in the case of water-closet cisterns in meter supplies; stop taps and stop valves which are optional on hot-water branch pipes **for heating purposes only**; fire hydrants and fire cocks.

CONNECTION OF WATER SUPPLIES

4. Before the connection for the supply of water can be made, or before any additional fittings can be connected to an existing service pipe, whether the premises are supplied by meter or otherwise, the plumbing work must be inspected and approved, **and plumbers and others are specially warned not in any case to connect to a service pipe or to a communication pipe laid for slaking lime, concreting, or other building purposes, and thereby supply water to the premises or to new fittings, without first receiving written consent from the authorised officer of the Waterworks Committee.** In case of neglect of this regulation, they will render themselves liable to the penalties comprised in the Waterworks Acts. New fittings replacing old ones may be connected, but notice of the same must forthwith be sent to the Waterworks Office.

COMMUNICATION AND SERVICE PIPES

5. (*a*) Only one communication pipe will be allowed to the same premises except by special arrangement.
(*b*) All service pipes must be brought out 3 ft. below street-level, and at least 1 ft. beyond the boundary of the premises at the point arranged as per Reg. No. 1.
(*c*)—

Description of Premises.	Number of Houses that may be supplied.	
	By a ½-inch Pipe.	By a ¾-inch Pipe.
Houses in block (without baths or water-closets) .	6	12
Houses in block (with baths only)	6	10
Houses in block (with water-closets only) . . .	6	10
Houses in block (with both baths and water-closets) .	4	7
Houses supplied separately .	One up to £70 rental	One above £70 up to £150 rental

Larger pipes than the above, for the supply of houses situate a long distance from the main, also pipes for the supply to warehouses, works, schools, etc., will be arranged on application.

. . . .

SIZES, ETC., OF SERVICE PIPES

7. (*a*) **Main Service Pipe.**—The main service pipe must not be of smaller diameter than the communication pipe, and must be continued to the branch stop tap in the last of a block of houses supplied together. In works, warehouses, etc., discretion will be used so as to secure the most efficient service.

(*b*) **Branches.**—Branch service pipes must not be less than ½ in. if laid to a bath or storage cistern, but may be ⅜ in. if supplying only one draw-off tap or one water-closet cistern.

(*c*) **Outside Pipes.**—All pipes laid in the ground outside buildings must be 3 ft. deep, unless special permission be given under exceptional circumstances.

(*d*) **Hot-Water Circulating Pipes.**—Hot-water circulating pipes between the boiler and cistern or cylinder must not be less than ¾ in. internal diameter, and the exhaust pipe must be of the same diameter as the circulating pipes. (For strength, see Reg. No. 9.)

(*e*) **Sanitary Precaution.**—No pipe will be allowed to be fixed or maintained in any ashpit, sough, or like position, where, in the event of the pipe becoming unsound, the water in such pipe would be liable to contamination.

MATERIAL OF PIPES

8. All communication and service pipes up to 1¼ in. diameter must be of lead, unless otherwise sanctioned by the Waterworks Committee. Iron pipe of 1½ in. and upwards should be of cast-iron, and protected; if wrought-iron is allowed, it should be tin lined with the tin lining tafted over at the joints. Any other kind of iron pipe can only be allowed under special circumstances, and on the consumer's responsibility for inconvenience or damage arising from corrosion. Copper pipes must be solid drawn, and of a minimum thickness of 14 imperial gauge.

STRENGTH OF LEAD PIPES

9. Lead pipes, both for hot and cold water, must be not less than the following strengths :—

⅜-inch diameter (for branches only),	5	lbs.	per lineal	yard.
½ ”	6	”		”
¾ ”	9	”		”
1 ”	12	”		”
1¼ ”	16	”		”
1½ ”	27	”		”

To assist plumbers in securing pipe of good quality, the Waterworks Committee are willing to test, free of cost, samples of pipe (say, of 1 yard in length), if sent to the Pipe Yard, Hyde Road, Gorton. Pipe should

stand a pressure of not less than 1000 lbs. to the square inch before bursting, and plumbers are recommended to purchase pipe under guarantee that it will withstand this pressure.

SUPPLIES OF WATER

10. (*a*) **Drinking Purposes.**—All water for drinking and cooking purposes must be supplied direct from the main, not from a cistern.

(*b*) **Baths, Lavatories.**—The cold supply to baths and lavatory basins may be taken either from the main or from a cistern. Every bath and lavatory must have a perfectly watertight waste plug, with chain, or a waste valve of approved pattern.

(*c*) **Water-Closets.**—Supplies to water-closets must be from cisterns approved and stamped. (Exception, see Reg. 3.) (Specification, see Reg. 24.) Water-closet cisterns and their working parts in water, though exempt from stamping in the case of meter supplies, must be made of non-corrosive material.

(*d*) **Urinals.**—Sparge pipes or other arrangements permitting a continuous flow of water, or for automatic flushing, are only allowed in meter supplies, whether from the main or from a tank. In other cases urinals must be supplied from an approved cistern, or by a self-closing tap of a non-concussive pattern, approved by the Waterworks Committee.

(*e*) **Boilers.**—No description of closed boiler will be allowed to be supplied direct from the main, but a cistern must be provided in every case. (See also Reg. No. 11 *re* Storage and Reg. No. 7 (*d*).) Copper boilers and cylinders in dwelling-houses are to be preferred in order to reduce the risk of explosion.

(*f*) **Fire Extinguishing Purposes.**—Direct supplies to sprinkler installations are allowed at fixed rentals, the sprinkler tanks being supplied by meter. Hydrants and firecocks in mills, works, etc., are supplied by meter. Stand-pipes kept on private premises must not be connected to the street hydrants except in case of actual fire. Arrangements for the purpose of practice may be made with the Waterworks Committee.

(*g*) **Lime Slaking, etc.**—Persons requiring water for lime slaking, etc., and other temporary purposes, must enter into arrangements as to charge and means of supply before commencing to use the water. Draw-off taps must be fixed on all pipes laid for building purposes, and the pipe fastened to a post, well bedded.

STORAGE OF WATER

11. (a) **Cisterns to be Provided.**—Storage cisterns to hold at least a half-day's supply, according to the average consumption, must be provided in all premises requiring a continuous supply of water for trading purposes, steam boilers, etc. This is necessary to secure a supply of water in case of accidents to or renewals of the mains, or alterations and connections of communication pipes.

(b) **Rain-Water, etc.**—Rain-water, water from wells, canals, or other sources will not be allowed to run into or be stored in cisterns supplied with Corporation water, unless by special arrangement for trading purposes. Nor can such water be allowed to be conveyed in pipes supplying water direct from the main.

(c) **Material of Cisterns.**—Storage cisterns must be constructed of slate, stone, concrete, iron, or other material approved by the Waterworks Committee, and, unless otherwise specially allowed, must be provided with a ball tap firmly fixed by screw and nut arrangement to the side of the cistern. All cisterns must be accessible for inspection.

OVERFLOW PIPES

12. (a) **As Warning Pipes.**—All overflow pipes must be fixed below the level at which the water is delivered into the cistern. Bath and lavatory overflows may be connected to the waste pipes, but with these exceptions, overflow pipes must be brought through an external wall, or fixed in some approved conspicuous position so as to act as warning pipes, and the discharge end must be at least 1 ft. below the ferrule in the cistern.

(b) **Size and Material.**—They must be of larger diameter than the supply pipe to the cistern, and not less than ¾ in. in a water-closet cistern, or 1 in. in a storage cistern or bath, must be attached to the cistern by means of a brass elbow ferrule and screw nuts, and must be of lead. In the case of large tanks, or under exceptional circumstances, special arrangements will be considered on application.

(c) **Protection.**—Where lead overflows are brought out in exposed positions, such as passages, at a less height than 7 ft., the ends must be protected by short lengths of iron pipe, and the lead tafted over.

STOP TAPS AND STOP VALVES

13. (a) **Size.**—All stop taps and stop valves fixed on service pipes must have a full waterway of at least the same bore as the pipes on which they are fixed. (See Reg. 21.)

(b) **Position.**—Stop taps or stop valves must be fixed on the service pipe inside and as near the private boundary as practicable, and not in passages, unless by special sanction. When inside stop taps are covered, the covers must be marked to indicate their position.

(c) **Protection.**—They must be protected when fixed outside a building (unless under a meter cover) by a cast-iron box weighing not less than 14 lbs., as per sample in the Testing Office, with a lead plug for stamping, and which must be cemented into a flag or concrete block 18 ins. square and 3½ ins. thick.

(d) **Spindles.**—When fixed in the ground, stop taps must have an extra strong spindle with a square head or an extra strong crutch, to which is to be attached an iron rod, the crutch of which is to be within 9 ins. of the ground level.

(e) **Branch Stop Taps.**—A stop tap must be fixed on the branch pipe in every house forming part of a group supplied by one communication pipe. When water-closets, baths, or hot-water systems are added to old properties not having their separate stop taps, a stop tap must be fixed on the new branch pipe.

MAKE OF TAPS OR VALVES

14. (a) **Screw-down Taps.**—All taps or valves to be fixed on pipes under pressure from the main must be of the screw-down slow-closing pattern, and, except in the case of slide valves, the valve must not be fast to the spindle.

(b) **Plug Taps.**—Plug taps or valves will only be allowed on distributing pipes from cisterns, unless sanctioned under exceptional circumstances. (See also Reg. No. 3.)

(c) **Self-closing Taps.**—Self-closing taps, unless supplied from a cistern, must be of an approved non-concussive design.

FLUSH PIPES TO WATER-CLOSETS

15. (a) **Lead.**—Flush pipes to water-closets must not be less than 1¼-in. internal diameter, and under ordinary circumstances must be of lead of not less than 8 lbs. per lineal yard for 1¼-in., and 10 lbs. for 1½-in. pipe.

(b) **Galvanised Iron.**—Where for special reasons it is desired to fix galvanised iron flush pipes, these will be allowed; but they must be attached to the cistern by a suitable flange and brass union joint, or some other approved screw arrangement.

(c) **Connections to Basin.**—The connections to the closet basin must be a good fit and perfectly watertight.

JOINTS

16. Copper-bit joints will only be allowed on waste, flush, or overflow pipes. Joints on all other pipes must be wiped plumbing, or such other joints, including brass unions, as may be approved.

METERS

17. The Waterworks Committee will provide and fix all water meters on service pipes and (when desired by the consumer) will also lay the pipe from the boundary of the premises to the meter and fix the stop tap at the cost of the consumer, who must, however, make any apertures in walls that may be necessary for the admission of the pipe, and make good the wall after the pipe is laid. When required by the Waterworks Committee, a stop tap or valve must be fixed on the outlet as well as on the inlet pipe of the meter.

NOTICE

18. Information from plumbers or other persons as to any infringement of these regulations will receive the immediate attention of the Waterworks Committee.

19. No deviation will be allowed from these regulations without the sanction of the Waterworks Committee, and any authorised plumber found lending his name to an unauthorised person will be struck off the list.

Note.—Any authorised plumber **who shall change his address** is directed to send particulars of such change to the Secretary, Waterworks Department, Town Hall, or his name will be omitted from the List subsequently printed.

TESTING AND STAMPING REGULATIONS

NOTICE

The Waterworks Committee will not be responsible for any breakage or injury that may occur to Water Fittings and Meters in the process of Testing and Stamping.

FITTINGS TO BE STAMPED

20. All taps, valves, and other water fittings must be of the pattern, material, and quality approved by the Waterworks Committee, and unless specially exempted must, before being fixed, be stamped by the authorised officer of the Committee. (See also Reg. No. 3.)

TAPS

21. **Bore, Strength, etc.**—All taps, as well as unions, must be made full bore (exception see Reg. 22 (*b*)), be well dressed, and free from sand. The taps must have well-finished raised seats,

not less than ⅛th of an inch thick, and slightly convex to allow the washer to properly bed without cutting; be of sufficient strength to resist a pressure of 300 lbs. per square inch; and, with the exception as per Reg. No. 14, must be on the screw-down principle, with loose valves and stuffing-boxes. The washers must be of the best material, and be approved by the Waterworks Committee.

BALL TAPS

22. (*a*) **Fullway.**—Fullway ball taps must be of a non-concussive design, and the diameters of taps and balls must be as follows:—

Diameter of Tap.	Diameter of Ball.
2 ins.	12 ins.
1½ "	10 "
1¼ "	8 "
1 "	6 "
¾ "	5½ "
½ "	4½ "

(*b*) **Direct-acting.**—Where a rapid flow of water is not necessary, direct-acting ball taps with restricted waterways will be allowed, the diameters of taps, balls, and waterways to be as follows:—

Diameter of Tap.	Diameter of Waterway.	Diameter of Ball.
2 ins.	1 in.	18 ins.
1½ "	⅞ "	14 "
1¼ "	¾ "	12 "
1 "	½ "	8 "
¾ "	⅜ "	7 "
½ "	⅛ "	4½ "

In direct-acting ball taps the raised seat must have a thickness of metal not less than ⅛ inch, must be well finished, with a slightly convex face, and the tap must be so designed as to make the seat accessible for examination. The washers must be of the best and approved material, and well secured in position.

BALL TAP SPINDLES

23. The rods or spindles of ball taps must be of cold-drawn copper, and of such length as will, when the tap is inverted for testing, resist a pressure of 300 lbs. to the square inch, and the valve must be perfectly tight at that pressure. They must also be of such sectional area as will prevent bending under working conditions.

FLUSHING CISTERNS

24. (*a*) **Principle of Construction.**—Cisterns for water-closets and urinals must be constructed on a waste-preventing principle as may be approved by the Waterworks

Committee. Automatic flushing cisterns will only be allowed on meter supplies.

(*b*) **Shape.**—They must have curved corners inside, and be at least 1 inch longer and ½ inch wider at the top than at the bottom, as a precaution against frost.

(*c*) **Material.**—The cisterns and all working parts in water must be of non-corrosive material, and the working must be easy in action. In lead-lined cisterns the lead must be of uniform thickness, not less than 4 lbs. to the square foot, and the weight be indicated thereon.

(*d*) **To be Valveless.**—Siphon cisterns only will be allowed, and they must have no communication with the flush pipe other than the siphon pipe.

Note.—To enable manufacturers and plumbers to work off existing stocks, this regulation will not be enforced until September 1st, 1910, up to which date the old regulation may be observed.

(*e*) **Siphons.**—The underside of the bend in the siphon pipe, or in the dome pattern, the top of the straight discharge tube must not be less than ⅛ inch above the side of the cistern, and the siphon must be capable of being brought into action when the water-level is 1 inch below the overflow.

(*f*) **Other Cistern Fittings.**—The **Ball Tap** must be attached to the end of the cistern by screw and nut arrangement; there must be no **carriers** for lifting the ball tap spindle; a **brass elbow ferrule** of not less than ¾ inch internal diameter for the overflow must be so fixed that the cistern will not give more than 2½ gallons flush when the water-level is 1 inch below the same; and must have a **brass outlet union** of sufficient internal diameter to take the 1¼-inch or 1½-inch flush pipe, as may be required. They must also have a **lead plug** inserted for stamping. (See also Regs. Nos. 12 and 15.)

SAMPLES OF APPROVED FITTINGS

25. Samples of approved taps and other fittings may be seen at the Testing and Stamping Office, but the Waterworks Committee will give due consideration to the claims of any other taps or fittings that may be submitted, and which, if satisfactory, will be stamped.

CHAPTER VII

THE FLOW OF WATER THROUGH PIPES AND ORIFICES—THE BURSTING STRENGTHS OF PIPES

THE term **Hydraulics** used in a general sense implies the science which treats of fluids in motion, but it is usual to include under the same heading the study of fluids at rest.

To the latter branch of hydraulics the term hydrostatics is applied, whilst the study of fluid in motion is dealt with under the head of hydrodynamics.

A Fluid is a substance that yields to any force, no matter how small, tending to change its shape or to cause movements of its parts among themselves.

A Liquid may be defined as a fluid whose volume will not increase beyond a certain point, and which offers great resistance to any decrease of volume.

A Gas is a fluid which tends to occupy as large a volume as possible, but which may be readily compressed into any volume, however small, so long as it remains a gas.

It will thus be seen that liquids are practically incompressible and inelastic, whilst gases possess the properties of compressibility and elasticity to a marked degree.

A Perfect Fluid is one whose parts can move among themselves without retardation.

Strictly speaking, there is no such thing as a perfect fluid.

Certain gases and the air closely resemble perfect fluids, but the passage of a solid body through these is resisted, and eventually the body is brought to rest when the force which put it in motion ceases to act.

A Viscous Fluid is one which continually retards the motion of its parts among themselves. The viscosity of fluids varies. Thus, linseed oil, honey, etc., are much more viscous

than water—*i.e.* they require a greater force to change their shape.

The equilibrium of fluids is not affected by their viscosity.

The fundamental property of a fluid at rest is embodied in the fact that its pressure on any surface is everywhere perpendicular to that surface.

An irregular shaped tank containing water is shown in Fig. 101. The water exerts a "pressure" perpendicular to the various surfaces, whether they be curved or straight, and no matter what angle they form with the horizontal.

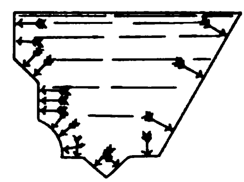


FIG. 101.—Diagram illustrating Water-pressure.

Pressure may be defined as a distribution of thrust over a surface. Pressure is stated in this country in "pounds per square inch" or tons per square inch.

Uniform Pressure refers to the equality of pressures acting over one or more surfaces. Thus if the pressure on the base of a tank be uniform, all parts of its surface will be sustaining equal pressure.

Total Pressure or thrust may be ascertained by multiplying area by pressure per unit area. Thus—

$$T_p = A \times P_u$$

Consider the case of a rectangular tank filled with water to a depth of 1 ft. The weight of water supported by each square foot of the bottom is 62·4 lbs.—*i.e.*, the weight of 1 cub. ft. of water at 4° C.

$\therefore$ the "pressure" on each square inch

$$= \frac{62 \cdot 4}{144} = \cdot 433 \text{ lbs.}$$

and the total pressure on the bottom

$$= \cdot 433 \times A$$

$$A = \text{area of bottom in square inches}$$

If the tank be filled to a depth of 6 ft., then the pressure per square inch on the bottom will be:—

$$6 \times \cdot 433 = 2 \cdot 598 \text{ lbs.}$$

Fig. 102 embodies several examples which illustrate this point. The free surface A of the water has a head, B, above the point R, and similarly the points S, T, U, V, W, X, Z are each subjected to a pressure due to the head of water measured vertically from each point to the free surface A.

It should here be noted that the varying volume of the water in the tank will not affect the pressure per unit area, if the head remains constant.

The size of the pipe connected with the tank likewise has no influence upon the pressure per unit area at Z.

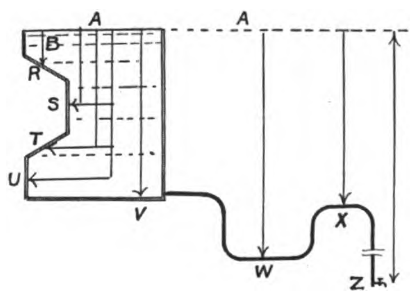


FIG. 102.—Diagram illustrating Water-pressure.

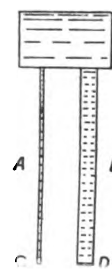


FIG. 103.—Diagram illustrating Pressure on Unequal Areas.

In Fig. 103 two pipes are shown attached to a tank which is filled with water. Pipe A is $\frac{1}{4}$ inch diameter and B is 2 ins. diameter; both terminate at a given level line. Assuming the "head" of water to be 15 ft., then the pressure per square inch at C D

$$= 15 \times \cdot 433 = 6\cdot 495 \text{ lbs. per square inch}$$

and the total pressure on blank end C of pipe A

$$\begin{aligned} &= 15 \times \cdot 433 \times \pi R^2 \\ &= 15 \times \cdot 433 \times 3\cdot 14 \times \cdot 125 \times \cdot 125 \\ &= \cdot 319 \text{ lbs. (approx.)} \end{aligned}$$

and the total pressure on D

$$\begin{aligned} &= 15 \times \cdot 433 \times \pi R^2 \\ &= 15 \times \cdot 433 \times 3\cdot 14 \times 1 \times 1 \\ &= 20\cdot 413 \text{ lbs. (approx.)} \end{aligned}$$

From the above it will be seen that the total pressure on any surface exposed to a uniform pressure

= pressure per sq. in. × area in sq. ins.

The relative total pressures on the surfaces C and D are as $P_1^2 : P_2^2$.

$$= \left(\frac{1}{4}\right)^2 : 2^2$$

$$= \frac{1}{16} : \frac{4}{1}$$

$$= 1 : 64$$

Example 1.—Determine the total pressure sustained by the interior surface of a cylinder under a mean "head" of 32 ft.; diameter of cylinder 1 ft. 9 ins., height 4 ft. 2 ins.

Total pressure

$$\begin{aligned}
&= \text{pressure per sq. in.} \times \text{area of cylinder} \\
&= 32 \times \cdot433\{(2\pi R^2) + (2\pi RH)\} \\
&= 13\cdot856\{(2 \times 3\cdot14 \times 10\cdot5 \times 10\cdot5) + (2 \times 3\cdot14 \times 10\cdot5 \times 50)\} \\
&= 13\cdot856(693 + 3300) \\
&= 13\cdot856 \times 3993 \\
&= 55327 \text{ lbs.}
\end{aligned}$$

Example 2.—Determine the weight required to balance a column of water acting on the surface of a safety valve, if the "head" be 56 ft. and the diameter of the valve $\frac{3}{8}$ in.

$$\begin{aligned}
\text{Weight required} &= \text{pressure in lbs. per sq. in.} \times \text{area in sq. ins.} \\
&= 56 \times \cdot433 \times \pi R^2 \\
&= 24\cdot248 \times 3\cdot14 \times (\cdot1875)^2 \\
&= 2\cdot68 \text{ lbs. (approx.)}
\end{aligned}$$

Example 3.—A safety valve is loaded with a weight of 4 lbs. The diameter of the valve is $\frac{5}{16}$ in.; determine the height of the column of water which can be supported.

$$\begin{aligned}
\text{Height of column} &= \frac{\text{Weight in lbs.}}{\cdot433 \times \pi R^2} \\
&= \frac{4}{1} \times \frac{1}{\cdot433} \times \frac{7}{22} \times \frac{32}{5} \times \frac{32}{5} \\
&= 120 \text{ ft. (approx.)}
\end{aligned}$$

Hydrodynamics is that portion of the science of hydraulics which treats of the flow of liquids, particularly water.

Owing to the highly complex character of the movements of the particles of a mass of water and of certain of the forces which obtain with such motion, also the fact that water is to some extent viscous, theoretical deductions in which water is treated as a perfect or non-viscous fluid are not in harmony with results obtained from practical observations and experiments.

To this extent it can be stated that hydraulics is not an exact science.

The fundamental principle of this subject embodies the law of falling bodies.

Every body in the universe exerts a certain attractive force on every other body, thereby tending to draw the bodies together.

Law of Gravitation.—The force of attraction between two bodies is directly proportional to product of their masses, and inversely proportional to the square of the distance between their centres.

If a substance is held in the hand, a downward pull is apparent, and if the support is removed the substance falls to the ground. The pull thus discovered is spoken of as the weight of the substance, but it really is the attraction which the earth exerts on the substance.

The Force of Gravity denotes the attraction between the earth and bodies on or near its surface. It acts in straight lines between the centre of the earth and the centre of the body, and it varies slightly at different points on the earth's surface.

If two equal spheres of iron and wood respectively were dropped from the same height in a vacuum, they would reach the ground at exactly the same instant.

If an equal mass of water accompanied the spheres of iron and wood in their fall, the three substances would reach the ground at the same instant (assuming that the water could be made to take and maintain a spheroidal shape).

If a body be dropped from a height, its velocity increases as it approaches the ground, owing to the force of gravity which acts upon the body as a constant accelerating force.

Experiments have proved that the force of gravity acting

on a freely falling body, is equivalent to giving the body a velocity of 32·2 ft. in one second.

If t = number of seconds during which the body falls,
H = height in feet that the body falls,
g = acceleration of gravity—*i.e.* 32 ft. per second per second,
V = velocity at the end of "t" seconds,

then $g = \frac{V}{t}$ ft. per second per second.

Since a body starts from rest, its average velocity at the end of "t" seconds is

$$\frac{O+V}{2} = \frac{V}{2} = \frac{gt}{2}$$

The space (H) through which the body falls = velocity × time.

$$= \frac{gt}{2} \times t = \frac{gt^2}{2}$$

and $V = gt$

$\therefore$ $H = \frac{V^2}{2g}$

and $V = \sqrt{2gh}$

Thus, a body starting from rest will have fallen 16·1 ft. at the end of the first second, and will then have a velocity of 32·2 ft. per second; at the end of the second second it will have fallen 64·4 ft. and attained a velocity of 64·4 ft. per second; at the end of the third second it will have fallen 144·9 ft. and have a velocity of 96·6 ft. per second.

The law of falling bodies applies equally to all matter, whether solid, liquid, or gaseous.

Consider the case of an open tank in which the free surface of the water is maintained at a fixed height above the centre of a circular orifice in the side of the tank, Fig. 104.

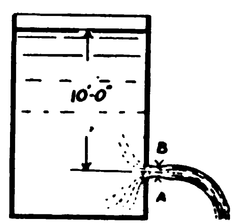


FIG. 104.—Apparatus illustrating the Law of Falling Bodies.

The theoretical velocity of the jet of water at the point A B will be

$$V = \sqrt{2gh}$$

and the actual velocity

$$V = c\sqrt{2gh}$$

owing to the resistance of the air, and the edges of the orifice, and the viscosity of the water.

The value of "c," which is spoken off as the coefficient of velocity, has been determined by experiments.

It varies with the character of the orifice, and to a slight extent with the head of water and the position of the jet.

As the result of numerous experiments, its value in connection with an orifice in a thin plate has been fixed at from ·960 to ·994, but for general purposes it can be taken as ·98.

Example.—What is the velocity of a jet of water issuing from an orifice in a thin plate in the side of a tank, the free surface of the water being maintained at a height of 10 ft. above the centre of the orifice?

$$\begin{aligned} V &= c\sqrt{2gh} \\ &= \cdot 98\sqrt{2 \times 32 \times 10} \\ &= 24{\cdot}8 \end{aligned}$$

The difference between the actual and the theoretical velocity can be demonstrated by arranging the jet to discharge vertically in an upward direction, as in Fig. 105.

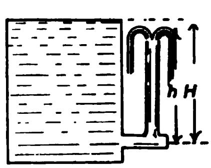


FIG. 105. — Apparatus demonstrating the Flow of Water through an Orifice.

It will be observed that the water will not rise to the height H of the free surface of the water in the tank, but will rise only to a height "h."

Under perfect conditions a liquid should rise to a height

$$\frac{V^2}{2g}; \text{ that is, H.}$$

It can be proved by experiments that "h" for water has a value of from ·960 to ·994: of H therefore, c (coefficient of velocity) is approximately ·98.

The volume discharged from an orifice is ascertained by multiplying the velocity by the area of the jet at the point of its maximum contraction or *vena contracta.*

The regular stream lines set up in the tank about the orifice gradually converge until they become practically parallel and perpendicular to the free surface of the water in

the tank. Towards the point A B, Fig. 104, the jet contracts and then expands beyond that point.

This contraction is known as the "contracted vein," or *vena contracta.*

The amount of contraction varies with the character of the orifice, and is greatest at a distance from the orifice equal to half the diameter of the same.

For thin plates the diameter of the *vena contracta* is ·8 of the diameter of the orifice.

$\therefore$ the volume discharged

$$= \cdot 8^2 \times a \times c \sqrt{2gH}$$
$$= \cdot 64 \times a \times \cdot 98 \sqrt{2gH}, \text{ (where "}a\text{" = area of orifice)}$$

The coefficient of efflux = coefficient of velocity × coefficient of contraction

$$= \cdot 98 \times \cdot 64$$
$$= \cdot 627$$

The formula for discharge from an orifice in a thin plate can be stated thus:—

$$D = k \times a \times \sqrt{2gH}$$

k = coefficient of efflux.
a = area of orifice.
D = discharge in cubic feet per second.

Example.—Find the discharge in cubic feet per minute from an orifice in the side of a tank in which the free surface of the water is maintained at a height of 16 ft. above the centre of the orifice. Diameter of orifice, 3 ins.

Discharge in cub. ft. per sec. $= k \times a \times \sqrt{2gH}$

" " per min. $= 60k \times a \times \sqrt{2gH}$

$$= \frac{60}{1} \times \frac{\cdot 627}{1} \times \frac{\pi D^2}{4} \times \sqrt{2 \times 32 \times 16}$$

$$\frac{37 \cdot 6}{1} \times \frac{22}{28} \times \frac{1}{4} \times \frac{1}{4} \times \frac{32}{1} = 59 \cdot 1 \text{ cub. ft.}$$

If a short tube whose length is from one and a half to three times the diameter of the orifice be fitted thereto, the coefficient of efflux is increased to approximately ·815—that is, the actual discharge may be taken as ·815 times the theoretical discharge.

If the inside edges be well rounded, and a conoidal or bell-

shaped mouthpiece be used, the coefficient of efflux will be increased to ·97 approximately.

Flow of Water through Pipes.—Owing to the many and varied conditions under which pipes are laid for the conveyance of water, it is impossible to obtain a formula which will be applicable to all cases.

Certain of the factors which influence the discharge of water through pipes are not constant, and in several of the more modern formulæ this feature is provided for by adopting a variety of values that are considered sufficiently empirical to cover the requirements of most cases.

The following factors involve a loss of head in a pipe line:—

1. The formation of eddies and the changing of potential energy to kinetic energy at the pipe entrance.
2. The friction between the water and the pipe surfaces.
3. Changes of direction, including bends and junctions.
4. Taps, valves, and variation of the diameter of the pipe that are met with in practice.

The chief of these are, friction between the pipe surfaces and the water, and the obstruction offered by bends, junctions, and valves.

The loss due to the former has been determined through the experiments of Reynolds, Froude, and others to be proportional to the square of the velocity approximately, where the speed is higher than the "critical velocity."

Professor Osborne Reynolds' demonstrations proved the fact that there are two laws affecting frictional losses due to flow in pipes. The apparatus used in his experiments consisted of glass tubes about 2 ins. in diameter and 4 ft. 6 ins. long, through which water from a tank was passed. A fine-bore tube at the entrance of each glass tube was made to deliver a fine stream of coloured water.

With velocities up to a certain point the thin stream of colour is maintained intact throughout the length of the tube, and is parallel to the sides of the same; but an increase of velocity above that point causes diffusion of the coloured stream line, owing to the formation of eddies.

The velocity at which the change from steady to unsteady or sinuous motion occurs is known as the "critical velocity."

With steady motion the friction varies directly as the

velocity, but when the critical value is reached the law is changed suddenly, and the resistance becomes approximately proportional to the square of the velocity.

Thus, if with a velocity of 10 ft. per second the friction is represented by a value x_1, then a velocity of 20 ft. per second will produce a friction value of $4x_1$, thus:—

$$10^2 : 20^2 :: x_1 : x_2$$
$$x_2 = 4x_1$$

In the case of bends, the loss of head depends upon the radius of the bend, and not so much upon the angle of deviation. Sharp bends and junctions offer considerable resistance to flow, but, as the results of numerous experiments, it has been demonstrated that bends constructed to a radius of thirteen times the diameter of the pipe do not impose additional resistance beyond that due to the internal area of the bend.

In straight pipes of even diameter and of considerable length, the frictional resistance of the interior surfaces is of primary importance besides which the loss of head due to the changing of potential to kinetic energy at the entrance to the pipe is insignificant.

If a horizontal pipe (Fig. 106) be discharging at full bore, the velocity will be the same at all points.

By inserting a number of vertical short tubes in the horizontal pipe, it will be observed that the water stands at successively decreasing heights in the vertical tubes.

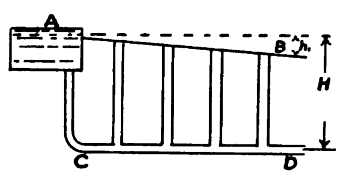


FIG. 106.—Hydraulic Gradient.

If the horizontal pipe possesses a uniformly smooth and even interior surface, the relative heights will be intersected by a straight line drawn from A, the free surface of the water, to B.

The head or distance h_1 represents the loss of head due to friction in the length C D. This loss is always proportional to the length of the pipe. The line A B is termed the hydraulic gradient.

Numerous formulæ have been deduced by engineers, from experiments on the flow of water through pipes, etc. The results obtainable for a given case, using different formulæ, vary from 5 per cent. to 30 per cent.

The following formulæ are simple, and give fairly reliable results:—

$$G = \sqrt{\frac{(3D)^5 \times H}{L}}$$

$$H = \frac{G^2 \times L}{(3D)^5}$$

$$L = \frac{(3D)^5 \times H}{G^2}$$

$$D = \frac{1}{3}\sqrt[5]{\frac{G^2 \times L}{H}}$$

in which
D = diameter of pipe in inches.
L = length of pipe in yards.
H = head of water in feet.
G = gallons per minute.

The use of logarithms is essential to the simple solution of problems by these formulæ.

Example.—Find the discharge in gallons per minute through a 4-in. cast-iron pipe, 650 yards long, the head of water being 280 ft.

$$\begin{aligned} G &= \sqrt{\frac{(3D)^5 \times H}{L}} \\ &= \sqrt{\frac{(3 \times 4)^5 \times 280}{650}} \\ \log G &= \tfrac{1}{2}(5 \log 12 + \log 280 - \log 650) \\ &= 2{\cdot}5152 \\ G &= 327 \text{ galls. per minute.} \end{aligned}$$

Example.—Find the diameter of a pipe which will discharge 150 galls. per minute under a head of 160 ft.; length of pipe being 400 yards.

$$\begin{aligned} D &= \tfrac{1}{3}\sqrt[5]{\frac{G^2 \times L}{H}} \\ \log D &= \tfrac{1}{5}(2 \log 150 + \log 400 - \log 160) - \log 3 \\ &= {\cdot}0729 \\ D &= 1{\cdot}18 \text{ (say } 1\tfrac{1}{4} \text{ ins.)} \end{aligned}$$

Example.—Find the head of water necessary to ensure a discharge of 35 galls. per minute through a 4-in. pipe 1680 yards long.

$$\begin{aligned} H &= \frac{G^2 \times L}{(3D)^5} \\ \log H &= 2 \log 35 + \log 1680 - 5 \log 12 \\ &= 3{\cdot}0882 + 3{\cdot}2253 - 5{\cdot}3960 \\ &= {\cdot}9175 \\ H &= 8{\cdot}269 \text{ ft. (8 ft. 3 ins. approx.)} \end{aligned}$$

Strength of Pipes.—The stresses that are set up in the walls of pipes, owing to internal pressures, are but imperfectly understood, especially in the case of pipes with thick walls.

The particles of metal forming the interior of a pipe are subjected to a greater stress than those forming the outer portion of the walls. Stresses other than those of a tensile character are developed, some of which may be due to uneven cooling of the casting.

Various formulæ have been devised, the chief of which are:—

1. Barlow's rule for thick-walled pipes:—

$$T = \frac{R \times P}{S - P}$$

$$P = \frac{S \times T}{R + T}$$

T = thickness of pipe wall in inches.
P = pressure in lbs. per sq. in.
S = tensile strength of the metal in lbs. per sq. in.
R = internal radius of the pipe in inches.
D = internal diameter of pipe in inches.

2. Rule for comparatively thin pipes:—

$$T = \frac{P \times R}{S}$$

$$P = \frac{S \times T}{R}$$

3. Rule for cast-iron pipes:—

$$T = \frac{(P + 100) \times D}{\cdot 4S} + \cdot 333\left(1 - \frac{D}{100}\right)$$

Formulæ 1 and 2 will give the bursting pressure for a pipe of known diameter and thickness of wall.

The "safe working pressure or thickness" can be determined by using a factor of safety.

The factors adopted lie between 3 and 10. For general use the former will be found sufficient.

Formula 3 gives the thickness of pipe wall necessary for a safe working pressure.

Example.—Find the "safe" thickness of a 4-in. cast-iron pipe which will sustain a working pressure of 200 lbs. per square inch. (Tensile strength of cast-iron = 18,000 lbs. per square inch.)

Using formula No. 3—

$$
\begin{aligned}
T &= \frac{(P+100)\times D}{\cdot 4S} + \cdot 333\left(1 - \frac{D}{100}\right) \\
&= \frac{(200+100)4}{\cdot 4 \times 18000} + \cdot 333\left(1 + \frac{4}{100}\right) \\
&= \cdot 1\dot{6} + \cdot 35 \\
&= \cdot 51 \text{ ins.}
\end{aligned}
$$

Example.—Determine the bursting pressure of a 2-in. copper pipe. The pipe wall is $\frac{1}{8}$ in. thick. (Tensile strength of copper = 30,000 lbs. per square inch.)

Using formula No. 2—

$$
\begin{aligned}
P &= \frac{S \times T}{R} \\
&= \frac{30000 \times \cdot 125}{1} \\
&= 3750 \text{ lbs. per sq. in.}
\end{aligned}
$$

Adopting a factor of safety of 5, the safe working pressure

$$
\begin{aligned}
&= \frac{3750}{5} \\
&= 750 \text{ lbs. per sq. in.}
\end{aligned}
$$

Example.—Determine the thickness of a 2-in. lead pipe which will sustain a working pressure of 200 lbs. per square inch, with a safety factor of 3. (Tensile strength of lead = 2500 lbs. per square inch.)

Using formula No. 1—

$$
\begin{aligned}
T &= \frac{R \times P}{S - P} \\
&= \frac{1 \times 200 \times 3}{2500 - (200 \times 3)} \\
&= \cdot 315 \ (\tfrac{1}{3} \text{ in. approx.}).
\end{aligned}
$$

The following results were obtained from a series of tests on lead pipes, carried out in the Municipal and Sanitary Engineering Laboratory, Municipal School of Technology, Manchester.

Internal Diameter of Pipe.	Strength, *i.e.* Weight per lineal yard.	Average or Mean Bursting Pressure of Three Tests in lbs. per sq in.
In.	Lbs.	
$\frac{3}{8}$	4	1520
$\frac{3}{8}$	5	1725
$\frac{1}{2}$	5	1265
$\frac{1}{2}$	7	1620
$\frac{5}{8}$	7	1280
$\frac{5}{8}$	9	1460
$\frac{3}{4}$	9	1165
$\frac{3}{4}$	11	1285
1	12	945
1	15	1160

Table of Tensile Strengths of Metals.

Metal.	Average Tensile Strength in lbs. per sq. in.
Copper (cast)	23,500
„ (sheet)	30,000
„ (wire) unannealed . . .	60,000
Gunmetal (copper and tin) . .	39,000
Brass (cast)	23,000
„ (wire) unannealed . . .	80,000
Tin (cast)	4,600
Zinc (cast)	3,700
Lead (cast)	2,000
„ (milled)—*i.e.* in pipes . .	2,500
Iron (cast)	18,000
„ (wrought)	60,000
Steel (cast)	80,000
„ (wire) unannealed . . .	156,000

CHAPTER VIII

DOMESTIC HOT-WATER SERVICES

Flow of Heat—its Application to Hot-water Services—Various Methods of Warming, Conserving, and Supplying Hot Water.

DURING recent years there has developed a continually increasing demand for hot-water services in houses having a letting value of from 6s. per week and upwards.

There is no doubt that an efficient hot-water heating and supply system is a boon in most classes of houses; and is indispensable where baths, sinks, and lavatories are used.

For warming and storing water, several methods are in vogue, each of which will be considered in detail.

Before doing so, it will be necessary to explain the natural laws that control and regulate the flow of heat.

Heat moves in three ways—"radiation," "conduction," and "convection." Each of these is embodied in all schemes for warming and storing water.

Radiant Heat is propagated in straight lines from bodies having higher temperatures to surrounding bodies having lower temperatures, without warming the intervening space.

The sun's rays are streams of radiant heat passing from the sun to the earth. In the case of an open fire, the heat rays are projected in straight lines to objects in the room without warming the air through which they pass.

The value of radiant heat varies inversely as the square of the distance from its source of heat.

Conductive Heat is observed in the transmission of heat through solid bodies. The outer particles first receive the heat and pass it onwards to other particles until the temperature of the body is uniform. No determinable movement of the

particles occurs during the conduction of the heat from one part of the body to the other parts.

Convective Heat is transmitted through liquids and gases by means of currents.

When water is heated in a vessel, the particles nearest to the bottom and sides of the vessel will be heated, and when a certain temperature is exceeded, they will expand, and thus become lighter per unit volume than those in the super-strata; they are then displaced by the heavier particles, which in turn receive heat and are forced upwards. Convection currents are thus set up in the water, thereby conveying the heat to all of its particles.

In a water-heating arrangement, the fire gives off rays of radiant heat, which strike the boiler and are conducted through its substance to the water in contact with its inner surfaces; the heat is then transmitted by convection currents throughout the body of water in the apparatus.

Fig. 107 shows a simple apparatus by which the principle of "convection currents" can be demonstrated.

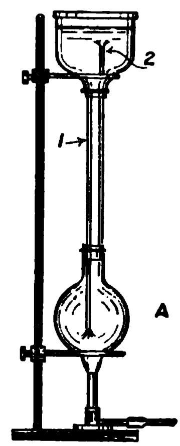


Fig. 107.—Convection Currents.

The glass flask A is connected with the glass jar by means of two $\frac{3}{8}$-in. glass tubes with indiarubber stoppers in the mouths of the vessels. Water containing an alkali, such as caustic soda or sodium carbonate, is placed in the flask, and the jar and tubes are filled with water containing a little phenolphthalein.

The Bunsen flame is applied to the flask, and it will be observed that a stream of coloured water is passing down the tube 1 whilst a similar stream is entering the jar through tube 2.

After a time the whole of the water is evenly coloured, and is raised to an almost uniform temperature.

The principle of convection is made use of in warming water, and causing it to be stored at high levels without the expenditure of energy other than the heat which is responsible for the formation of convection currents.

The rate of flow in an apparatus similar to Fig. 108 depends

upon the relative temperatures of the two columns of water in the pipes A and B.

If heat be applied by the aid of a Bunsen burner to the point C, and the stopcock D be closed, the water in pipe A will expand and rise to a height x. The difference in level, h_1, between column A and the colder column B is spoken of as the "circulating head," and it is to this that the rate of flow or velocity is due.

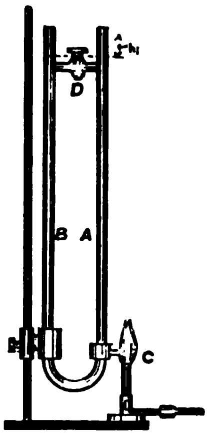


Fig. 108.—Balancing Columns of Hot and Cold Water.

It will be observed that the value of the difference, h_1, increases with the height of the two columns of water and the difference of their temperatures.

Experiments have proved that water does not expand at a regular rate between its temperatures of maximum density and boiling-point.

Fig. 109 shows the percentage increase per unit volume of water during an increase oft emperature from maximum density (*i.e.* 4° C.) to 140° C.

The variation of the rate of expansion is noticeable by comparing the increase of 1 per cent. between 4° and 45° C., with the further increase of 2·5 per cent. for a rise of temperature from 45° to 90° C.

The velocity of flow of water through the pipes of a circulation arrangement is difficult to determine with any degree of accuracy. Various formulæ are in use for the purpose, but the variation of the conditions under which they must be applied, and the fact that frictional resistances for such conditions have been only approximately elucidated, restrict their scope and general utility.

Hood was the first to attempt the determination of velocities. The basis of his calculations is founded on the law of falling bodies, in which $V = \sqrt{2gh_1}$, equals the theoretical velocity in feet per second. The value of h_1 is the height in feet of the circulating head h_1, Fig. 108.

It is assumed that the theoretical velocity is equal to the

speed that a freely falling body would acquire whilst falling through a height equal to the distance h_1.

It will thus be seen that the difference of temperature of the two columns of water and the height of the columns will influence the rate of flow; an increase of the value of these factors will cause an increase of velocity.

When working under normal conditions the velocity never reaches the "critical speed"; therefore the friction factor is

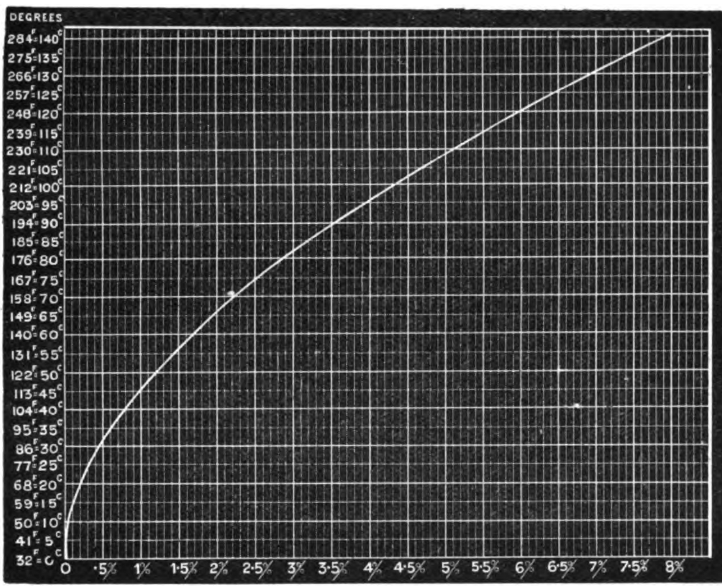


Fig. 109.—Chart showing Increase of Volume of Water during Heating.

governed by the first law for velocities, and consequently varies directly as the velocity and inversely as the diameter of the conduit.

Under practical conditions the retardation due to friction is a factor of considerable importance.

Experiments have proved that the mean velocity obtainable varies from about 5 per cent. to 15 per cent. of the theoretical value.

The currents of water in the central part of the flow travel at a higher velocity than those nearer the pipe wall, whilst those in contact with it flow at a much reduced rate owing to friction.

L

Assuming that the friction factor for a pipe of 1 in. diameter $= \cdot 05$, it is possible to approximately determine the mean velocity of flow for a stated case.

Example.—Find the velocity in feet per minute of the water in the circulation apparatus, Fig. 110, if the height of the circuit be 10 ft. and the average temperature of the water columns T_1 and T_2 be 120° and 180° F. respectively, and the diameter of the pipe be 2 ins.

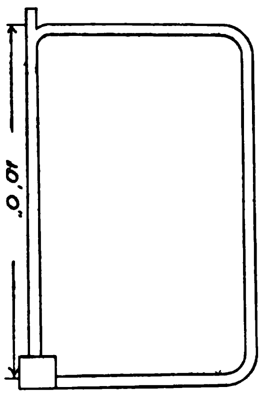


Fig. 110.—Circulation of Water by Convection Currents.

In this case it will first be necessary to find the value in feet of the circulating head h_1. Between the given temperatures it will be noticed by reference to Fig. 109 that the curve is almost straight, and although the increase in volume from 40° F. to 212° F. $= 4 \cdot 5$ per cent., the expansion, which is relatively higher between 120° and 180° F., is approximately at the rate of 6 per cent. over 172° F.

As the temperatures mentioned are within the range which usually obtains in practice, the rate of expansion will be deduced from a 6 per cent. increase over 172° F. instead of the lower figure 4·5.

$$h_1 \text{ for 1 ft. head} = \frac{180 - 120}{172} \times \frac{6}{100}$$

$$\text{,, 10 ,,} = \frac{60}{172} \times \frac{6}{100} \times \frac{10}{1}$$

$$= \frac{9}{43} \text{ ft.}$$

Assuming a friction factor of ·05.

$$Vm = \cdot 05 \sqrt{2gh_1 d}$$

$$= \cdot 05 \sqrt{2 \times 32 \times \frac{9}{43} \times 2}$$

$$= \cdot 05 \times 8 \sqrt{\frac{9}{43} \times 2}$$

$$= \cdot 4 \times \frac{4 \cdot 24}{6 \cdot 55}$$

in which

Vm = mean velocity in feet per second.

$g = 32 \cdot 2$.

$h_1 = \frac{9}{43}$, as previously determined.

d = diameter of pipe in inches.

$$\text{the velocity per minute} = \cdot 4 \times \frac{4 \cdot 24}{6 \cdot 55} \times \frac{60}{1} = 15 \cdot 5 \text{ ft.}$$

The quantity of water which will pass along such a circuit in one minute

$$= Vm \times a \qquad a = \text{cross-sectional area of the pipe.}$$
$$= 15{\cdot}5 \times \pi R^2$$
$$= \frac{15{\cdot}5}{1} \times \frac{22}{7} \times \frac{1}{12} \times \frac{1}{12}$$
$$= \frac{341}{1008} \text{ cub. ft.}$$

The arrangements made for storing the heated water in convenient positions and for delivering adequate supplies to fittings in a given area of supply may be classed as:—

1. Those depending entirely upon convection currents.
2. Those in which circulation is aided by mechanical effort.

The former includes the following systems:—

(*a*) Side and back boiler with or without pressure.
(*b*) The quick service or "push boiler."
(*c*) The tank system.
(*d*) The cylinder system.
(*e*) The cylinder system with secondary circulation.
(*f*) The cylinder system and tank system, or reserve storage system.
(*g*) Special systems combining the functions of domestic services and house-warming, also systems for preventing the deposit of salts of lime.

The latter includes all systems in which the water is circulated by means of pumps or similar mechanism.

The simplest form of hot-water supply arrangement is shown in Fig. 111.

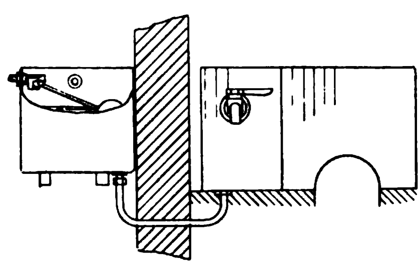


Fig. 111.—Simple Hot-water Service.

It consists of an open boiler fitted in the back and one side of the kitchen grate. It is fed by means of a side tank fixed so that the maximum water-level will be maintained 2 ins. below the top of the boiler.

The hot water is drawn from a cock fixed directly to the boiler.

Fig. 112 shows a modification of this system. The pipe *a* conveys the heated water to the fittings, and the position of the cistern *b* commands the levels of the highest fittings to be supplied.

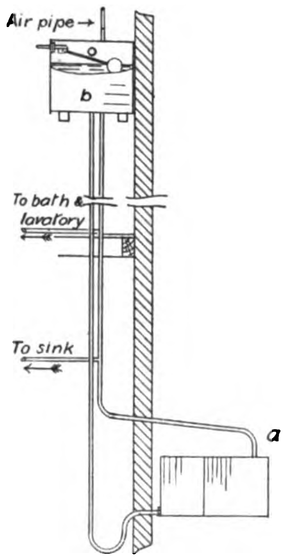


FIG. 112.—Simple Hot-water Service under head.

This arrangement has only the merit of lower cost. The volume of hot water that can be stored depends entirely upon the capacity of the boiler, which is in turn limited by the proportions of the fire grate.

The "push boiler" is a local term used in connection with a modification of the previously mentioned arrangement. Fig. 113 shows this system. The boiler is usually of cast-iron and of large capacity, supplied with cold water through the pipe A. The pipe C conveys the heated water to the sink. When hot water is required the tap B is opened, and the cold water entering the boiler through A forces the hot water through the pipe C.

In many cases the air pipe is dispensed with, but the risk of explosion of the boiler during frosty weather is increased

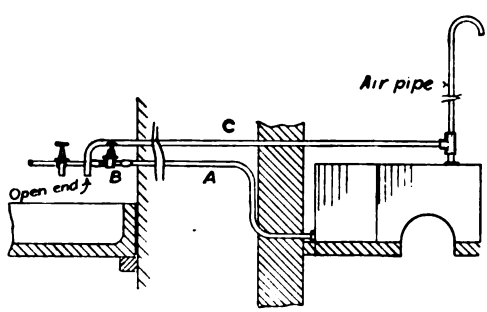


FIG. 113.—Simple Hot-water Service; Direct Connection with Cold Service Pipe.

thereby. The air pipe is shown fixed in the flue with the end turning downwards.

This system is very unsatisfactory, as the amount of hot water available is small and the risk of the water content being evaporated and damage resulting to the boiler is considerable.

The Tank System consists of an arrangement whereby the heated water is stored in a convenient position above the source of heat.

There are two types of this system, one in which the tank is open at the top, and is fixed at the same level as the cold supply tank, and another consisting of a closed tank fixed some distance below the supply tank.

Fig. 114 shows a line diagram of the former. The tanks are fixed at a level well above any fitting deriving a supply therefrom. The flow pipe A projects into the tank to the extent of from 9 to 12 ins., and the return pipe terminates several inches above the bottom of the boiler.

The hot-water supply branches are taken from the flow pipe, or a special pipe is provided as shown in dotted lines at B.

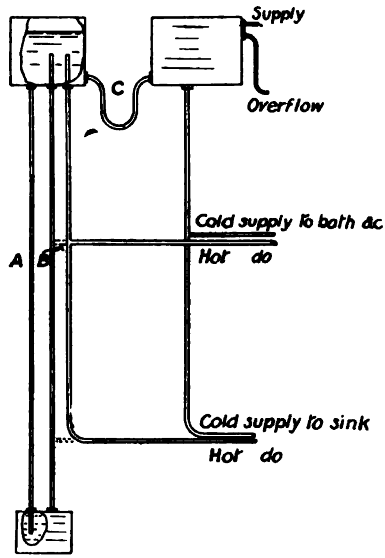


Fig. 114.—System with Open Tank.

The trap formed in the cold supply pipe C prevents local circulation between the two tanks.

Fig. 115 shows the second type of tank system.

The hot supply pipe is branched into the air pipe, thereby ensuring a supply of hot water.

The chief defects of these systems are:—

1st. The length of the circulating pipes, which imposes unnecessary friction upon the flow of water between the boiler and the storage tank.

2nd. Loss of heat by radiation from the circulating water.

3rd. The risk of the boiler being emptied during periods of

frost, or at other times when the cold supply is shut off, a condition which may result in fracture of the boiler owing to overheating, and rapid cooling caused by the sudden entry of water.

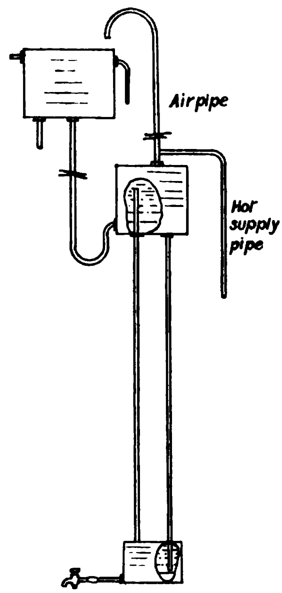


FIG. 115.—System with Closed Tank.

4th. The limited character of the hot-water supply.

5th. The tank is usually fixed in an inaccessible position, and the heat evolved from its surfaces is lost.

The only advantage which it possesses is the good delivery of hot water owing to the water being stored in bulk above the delivery levels.

The Cylinder System consists of an arrangement of pipes, boiler, and cylinder, whereby the latter is fixed as near to the boiler as possible. The cylindrical shape of the reservoir is adopted on account of the resistance which such shape offers to distortion from internal pressures.

There are several methods in vogue for fixing the cylinder and pipes, but they only differ in detail.

Fig. 116 shows an outline of the cylinder system. It will be observed that the cylinder occupies a position on one side of the kitchen fireplace, thereby reducing the length of the circulation pipes to a minimum.

An air pipe, exhaust pipe, or expansion pipe is connected to the top of the cylinder, and all hot supplies are branched from this pipe. Under normal conditions the cylinder cannot be emptied when the cold supply is shut off.

The flow pipe is shown in this example connected to the cylinder near the top of the same. This practice is not generally adopted; in most cases the flow pipe is made to enter the cylinder about 6 ins. above the return pipe, as shown by the dotted line A. When connected in this manner, the whole of the water-content above the flow pipe in the cylinder has to be heated before hot water can be drawn from the apparatus.

The disadvantage of this arrangement is most marked during the early period of the day, when there is a moderate demand for hot water.

If the flow pipe be connected near to the top of the cylinder, a quantity of hot water will be available within a reasonable period after the boiler fire is lighted.

The return pipe must enter the cylinder near to the bottom,

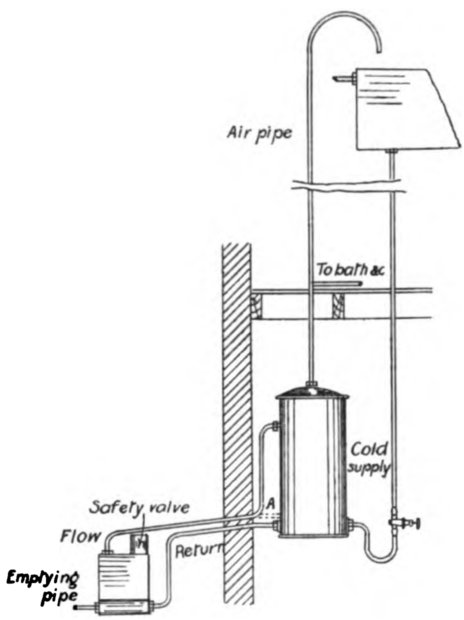


FIG. 116.—Cylinder System.

and the cold supply connection should be made at or about the same level.

The air pipe may be continued through the roof or terminated two feet above the cistern, the end being turned over the cistern but kept well above the water-level.

The cold supply pipe should not be used for any purpose other than that of supplying the cylinder with cold water.

In many cases it is considered advisable to fix the cylinder in the bathroom on the first floor instead of in the kitchen. Although an additional length of circulation pipe is necessary, no reasonable objection can be sustained against the arrange-

ment, whilst the advantage of utilising the heat evolved from the cylinder for airing linen, etc., and warming the bathroom should not be under-estimated.

Fig. 117 shows a hot-water apparatus in which the cylinder is fixed in the bathroom on the first floor directly over the boiler, and is provided with a wooden enclosure that forms a linen-closet. This arrangement proves very suitable for small houses.

The cold supply is controlled by the cock A, the position

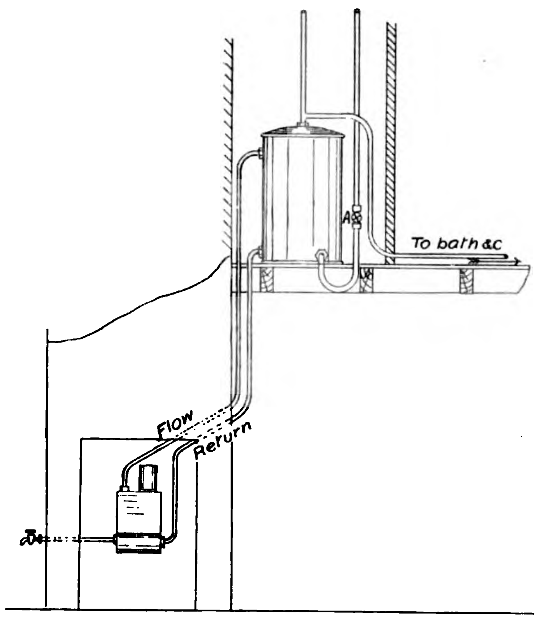


Fig. 117.—Cylinder System with Cylinder on First Floor.

of which renders it easier of access than that usually adopted near to the cold supply tank.

Horizontally-fixed Cylinders are occasionally adopted under certain conditions where floor space is not available for the vertical position. Care is required in arranging the pipe connections to avoid the mixing of the entering cold water with the stored hot water.

This position is usually adopted where cylinders are fixed in kitchens or sculleries in which the floor space is required for other purposes.

It is also adopted occasionally in bathrooms, when the cylinder is fixed overhead on account of lack of space.

Fig. 118 shows a satisfactory arrangement of pipes in connection with a cylinder fixed horizontally.

The flow pipe enters about 6 ins. below the top of the cylinder, and the return is taken from the bottom at the opposite end. This ensures warming of the cylinder-content,

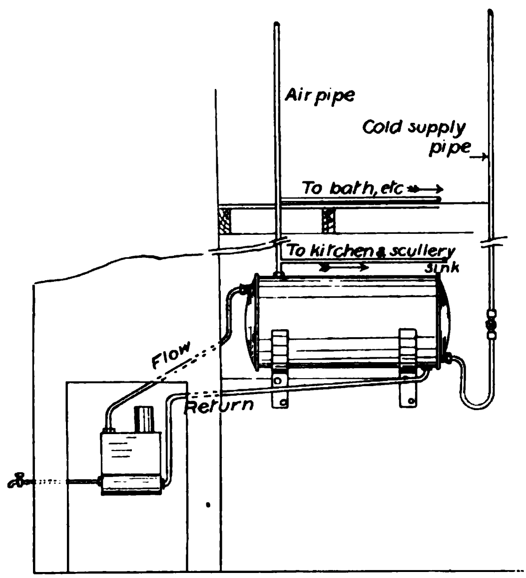


Fig. 118.—Horizontally-fixed Cylinder.

and the provision of a stratum of hot water at the top of the cylinder.

The cold water is made to enter in a horizontal direction, so that it does not mix with the hot water.

The cylinder supports must be of sufficient width to prevent damage to the cylinder if the latter be of copper.

Secondary circulation.—The travel of the water between the boiler and the cylinder is known as the "primary circulation," and the pipes through which this takes place are designated the "primary flow and return pipes" respectively.

If the fittings requiring hot supplies are situated some distance from the storage cylinder, a quantity of cold or

"dead" water will be delivered at each tap before hot water is available. In addition to the waste of water that this method of supply entails, there is also the loss of time of the user of the fitting to consider.

These disadvantages can be overcome at a slightly increased cost over the ordinary method by a modified arrangement of the pipes which will cause the hot water to circulate from the cylinder, past the various fittings, and back again to the

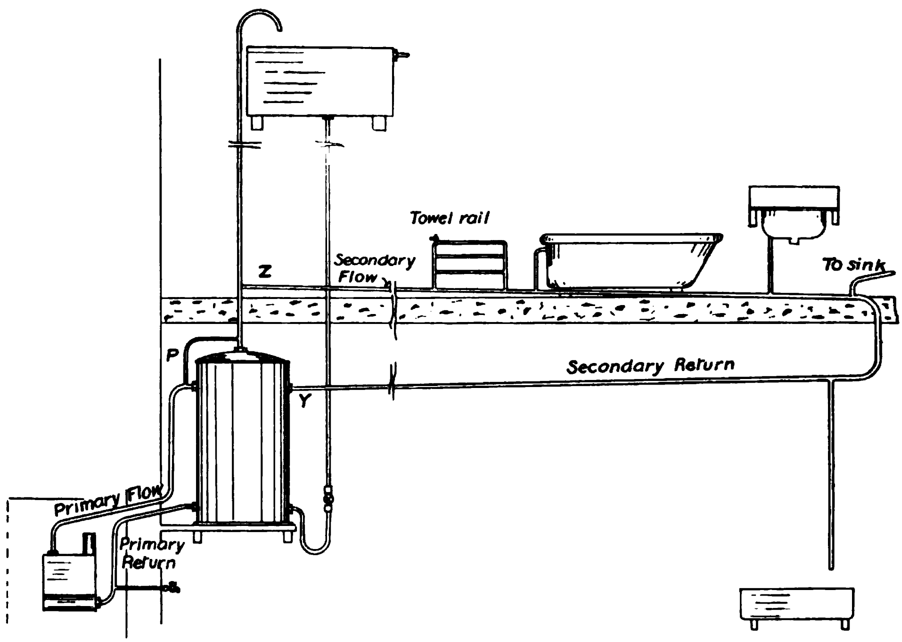


FIG. 119.—Cylinder System with Secondary Circulation.

cylinder or boiler. The term "secondary circulation" is applied to this flow of water, and the pipes through which it passes are known as "secondary flow and return pipes."

The pipe route is devised with a view to reducing to a minimum the length of the branch pipes to fittings, so that hot water will be drawn almost immediately the taps are opened.

Fig. 119 shows an apparatus with a simple form of secondary circulation. The cylinder is fixed in the kitchen,

and the air pipe is taken vertically to a point above the cold supply cistern. The secondary flow pipe is branched from the air pipe, and has a gradual fall of not less than $\frac{1}{16}$ in. per foot to the point where it turns vertically, and is afterwards continued to the cylinder with a slight fall.

A by-pass pipe, P, is provided between the primary and secondary flow pipes, through which a stream of hot water is delivered direct from the boiler into the secondary circulation.

The pipe Z Y must have a slight declination from Z to Y, to prevent the formation of air-pockets, or locks, which would tend to retard, and possibly stop entirely, the secondary circulation.

The force causing movement of the water in this part of the system is due to the difference in temperature of the water in the column Z Y, and that in the column P Z; the water in the former loses heat whilst travelling from Z to Y, and consequently is denser than that in Z P.

It is often necessary to arrange a secondary circulation in connection with a system having the cylinder on the first floor.

The latter condition should be avoided where possible; it is not so satisfactory as that shown in Fig. 119.

Fig. 120 shows the pipe routes for the primary and secondary circulation where the cylinder is fixed on the first floor.

It will be observed that the secondary return joins the primary return, and that the pipe rises from the junction to the air pipe on the top of the cylinder. The pipes marked X are branches to fittings.

It is necessary to insert a reflux or back-pressure valve at A to prevent the cold water from the primary return pipe entering the secondary return when the two lower branches are discharging water. This device is also necessary to retain the water in the cylinder when the cold supply is shut off and the hot supply taps are opened.

If this precaution be omitted, the two branches on the secondary return will deliver a mixture of hot and cold water owing to a temporary reversal of the current in this pipe when the taps are opened.

Under the best conditions reflux valves fixed in such

positions are liable to failure, which may cause a stoppage of the secondary movement, or may allow cold water to be delivered at XX.

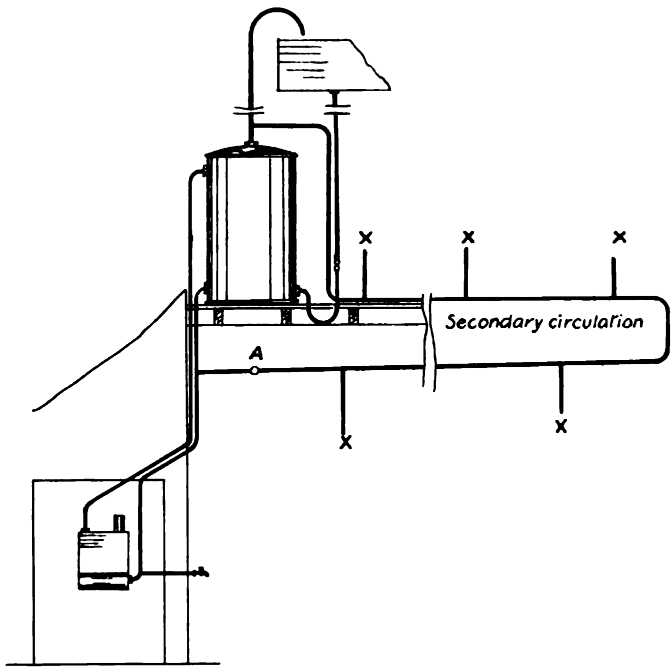


Fig. 120.—Cylinder on First Floor with Secondary Return.

Fig. 121 shows a part section through a reflux valve. The flap is usually made of copper, and is loosely hinged over a ground face of gunmetal. Heavy flaps should not be used, as they retard the flow of water, and often are responsible for a total stoppage of the same.

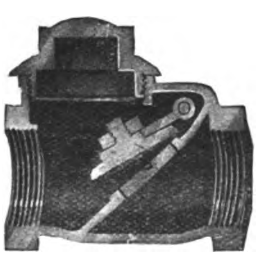


Fig. 121.—Reflux Valve.

In systems where hot supplies are fixed on the second and upper floors, the ordinary method of secondary circulation is inadequate to give a full delivery to each fitting in the event of a combined demand from all or the major portion of the fittings.

Fig. 122 shows a secondary circulation arrangement which would not be satisfactory. When a supply of hot water is required simultaneously on the three floors, the pipes marked A would receive the bulk of the supply, whilst those on the second and third floors would be devoid of water.

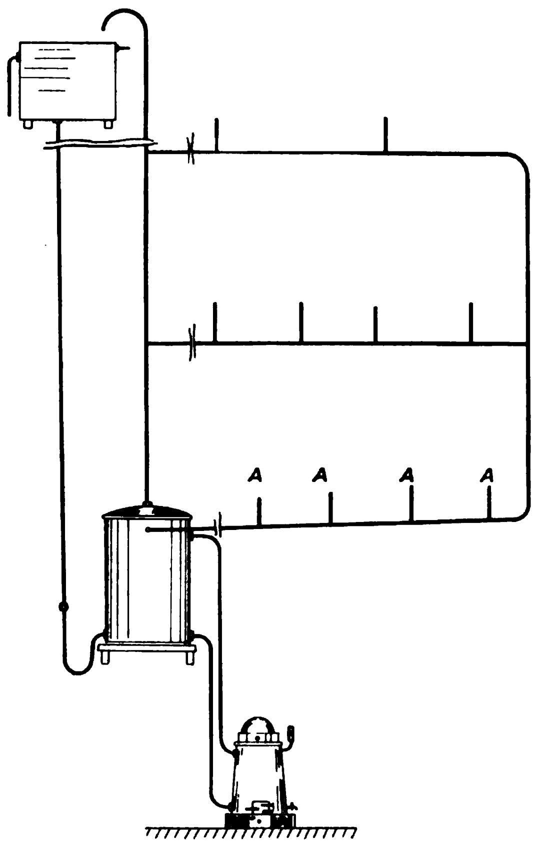


FIG. 122.—Defective Secondary Circulation.

The importance of having a cold-water supply pipe of large diameter cannot be overrated. This is particularly noticeable if the supply pipes are of considerable length. The friction greatly reduces the mean velocity of the water, and consequently the volume delivered is much less when the cold supply pipe is of comparatively small diameter.

The Cylinder and Tank System Combined differs from

the cylinder system, owing to the additional storage provision which is made in the high parts of the system.

In large buildings hot-water supplies are required in widely separated positions on the various floors. The system shown in Fig. 122 would be totally insufficient unless the pipes were large enough to enable them to cope with the maximum demand—a condition which is not adopted on account of expense.

To ensure a full supply at all the fittings, one or more hot-water storage tanks are fixed in advantageous positions on the secondary circulation.

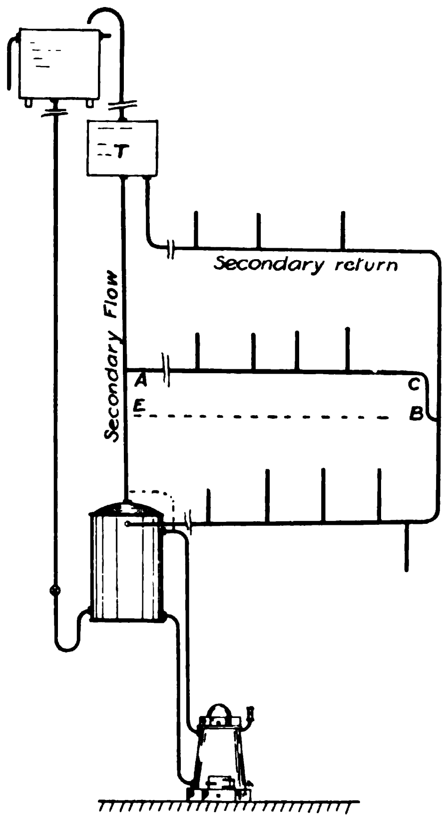


FIG. 123.—Cylinder and Tank Combined System.

Fig. 123 shows a simple arrangement of the cylinder and tank system, which is a modification of Fig. 122. The reserve tank T is fixed at a commanding level; the air pipe which enters it acts as a secondary flow conduit, whilst the secondary returns provide for a circulation of water past the various fittings on the three floors, and are eventually connected to the cylinder about 9 ins. below the top.

The branch A B supplies a current of hot water to fittings fixed on the second floor.

It will be observed that instead of branching this pipe into the main vertical return at D, a short column of water, B C, is formed by continuing the pipe vertically to the point B.

This arrangement ensures a reasonable circulation of the water in A C, owing to the lower temperature, and consequently the greater density of the water in B C as compared with that in A E.

The fall available from A to C would be insufficient to produce a movement of the water in this length of pipe.

The position chosen for the connection of the secondary return to the cylinder will have an important effect upon the satisfactory working of the system.

In some instances this pipe is branched into the primary return, or is made to enter the cylinder near to the bottom of the same.

Fig. 124 shows a faulty arrangement on the lines indicated. The secondary return joins the cylinder at A. The major portion of the water delivered at the fittings marked X will pass from the cylinder through the connection A, and in consequence will be lukewarm instead of hot.

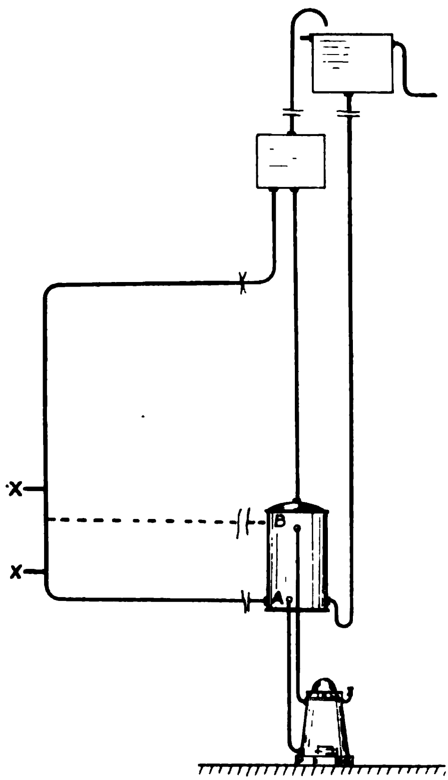


Fig. 124. — Cylinder and Tank Combined System, showing Defective Connection of Secondary Return.

If the connection be made as indicated by the dotted line B, hot water will be obtainable at these fittings, even when there is only a small quantity of hot water in the top of the cylinder in addition to that in the reserve tank.

If it is required to serve fittings that are situated below the cylinder, and to maintain a circulation past the same, it will be

necessary to form a dip in the secondary return. It should be borne in mind that such a course will result in a reduction of the circulating head, and consequently of the velocity of the secondary circulation.

Cylinder tank systems require adequate heating surfaces in the boilers which serve them.

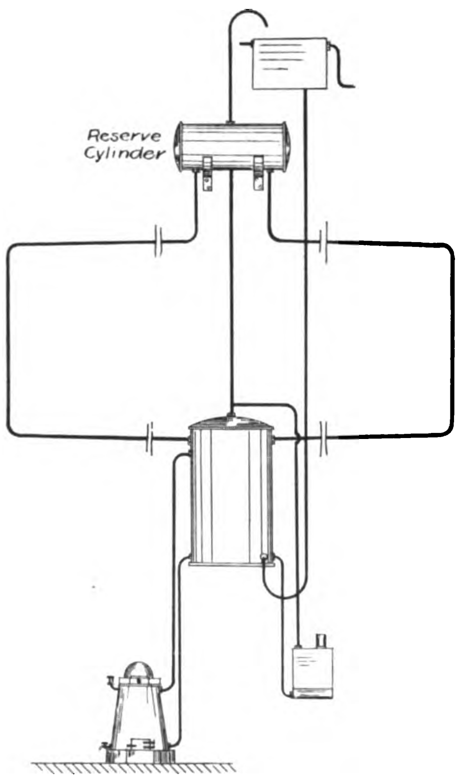


Fig. 125.—Cylinder and Tank Combined System with Duplicate Boilers.

An attempt to put the whole of the duty upon a kitchen-range boiler invariably ends in failure. The maximum effective duty of these boilers is soon reached, and is rarely sufficient for the requirements of an installation of moderate size.

They may be used with advantage to supplement the independent boiler, but to ensure success the inclusion of the

latter or some form of additional heating medium in a large system is an absolute necessity.

Fig. 125 shows one method of connecting a duplicate system of boilers.

The primary flow pipe from the kitchen-range boiler is connected to the secondary flow pipe. This connection will permit of a delivery of hot water into the reserve storage cylinder in the early portion of the day, before the fire is lighted under the independent boiler.

In large mansions it frequently happens that there are several groups of fittings which cannot with satisfaction be supplied from one reserve storage tank, owing to the situations being some distance apart.

Where possible, a storage tank should be fixed above each group of fittings, care being taken to ensure a full supply to the fittings by grading the sizes of the secondary circulation pipes, and providing reserve tanks of sufficient capacity.

Fig. 126 shows in diagram form a large installation possessing two reserve vessels. The secondary flow, A, is continued vertically to a point above the cold supply tank.

A branch, B, supplies the reserve tank C, from which the secondary returns D and F convey the hot water past the various fittings and eventually are connected together before entering the cylinder.

A second branch is inclined from the pipe A to the secondary cylinder G, which provides a supply of hot water to the group of fittings connected with the secondary returns K J.

Several radiators or towel - rails are connected to the secondary returns where the latter pass through dressing-rooms in which lavatories are fixed.

The by-pass P conveys a quantity of hot water into the secondary flow pipe immediately circulation is set up, and thereby ensures the delivery of hot water into the reserve vessels C G, before the temperature of the cylinder-content is appreciably increased.

In all cases the cold supply pipe must be connected either to the cylinder or to the primary return pipe; on no account must it be connected to the reserve storage tank. If this precaution be not observed, cold water will be drawn at the hot supply taps.

Where radiators or towel-rails are to be connected to hot-water services, additional boiler surface must be allowed, to balance the loss of heat by radiation from these fittings.

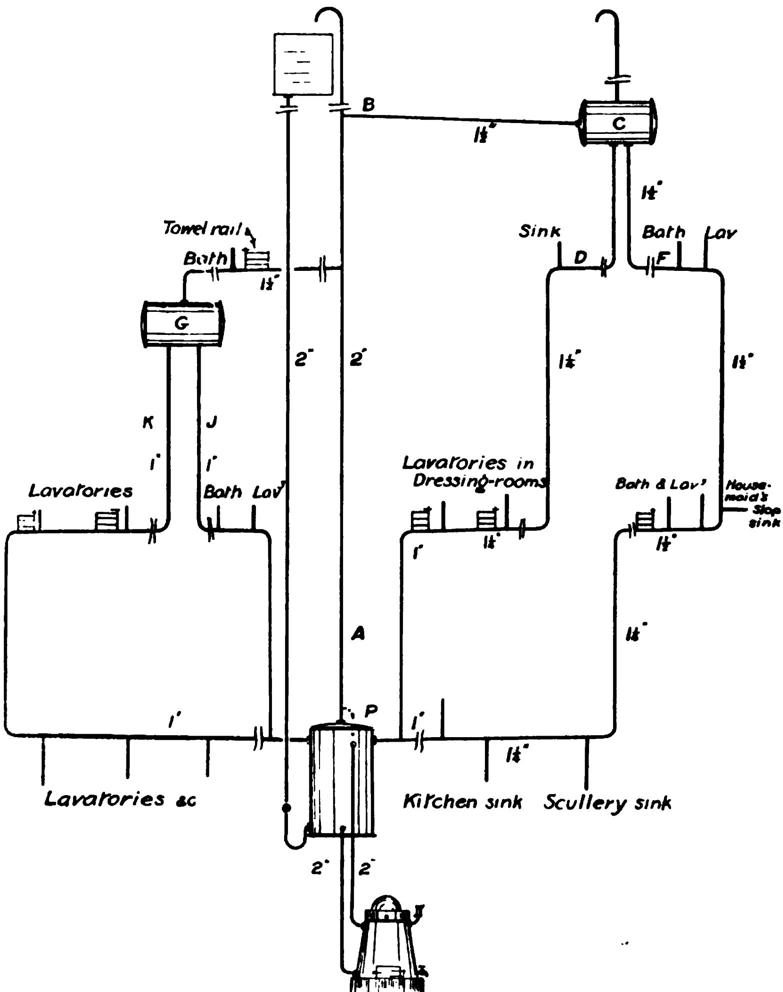


FIG. 126.—Hot-water Services for a Large House.

Hot-water services for suites of offices require special consideration. The demand upon the stored hot water is exceptionally heavy at certain periods during each day. It is,

therefore, necessary to provide reasonable storage accommodation which will meet the maximum demand. Moreover, the boiler surface must be sufficient to raise the content of the storage cylinder and tanks from 50° F. to 180° F. within two hours.

Caretakers are usually available to control the firing of the boilers; with care and experience the regulation of the working of the apparatus can generally be made to meet the requirements of the occupants of the offices.

Fig. 127 is a diagram of a scheme suitable for a block of offices four storeys high. Four ranges of lavatories having eight basins in each range, and also four sinks, are to be supplied with hot water.

The total storage capacity of the cylinder and tank is 100 galls., the latter vessel holding 60 galls., whilst the former contains 40 galls.

The secondary flow pipe is 2 ins. in diameter, and the secondary return is of the same size from A to B; at the latter point it is reduced to $1\frac{1}{2}$ ins., and at C it is again reduced in diameter to $1\frac{1}{4}$ ins. It is continued in the latter size to the cylinder, which it enters about 9 ins. below the top.

The grading of the sizes of the secondary circulation pipes will ensure a full delivery simultaneously at all the lavatory supplies if required.

An inclination of not less than $\frac{1}{16}$ in. per foot-run must be given to the portions of the service pipes that pass beneath the ranges of basins.

The two portions of the circulation arrangement that are marked D E provide additional supplies of water to the ranges on the first and second floors. They are inclined from D to E, and are continued vertically for a length of from 2 to 3 ft. before being connected to the secondary return at E. This arrangement ensures circulation in these parts.

The hot water is supplied to the fittings by the four routes marked 1, 2, 3, and 4 on the diagram. The bulk of the water delivered to the range on the ground floor will pass through the connection marked 2, this being the line of least resistance. The supplies to the ranges on the first and second floors will be obtained principally through the connections marked D, and

consequently from the connections 1 and 3. The range on the third floor will derive its supply through the connection marked 4.

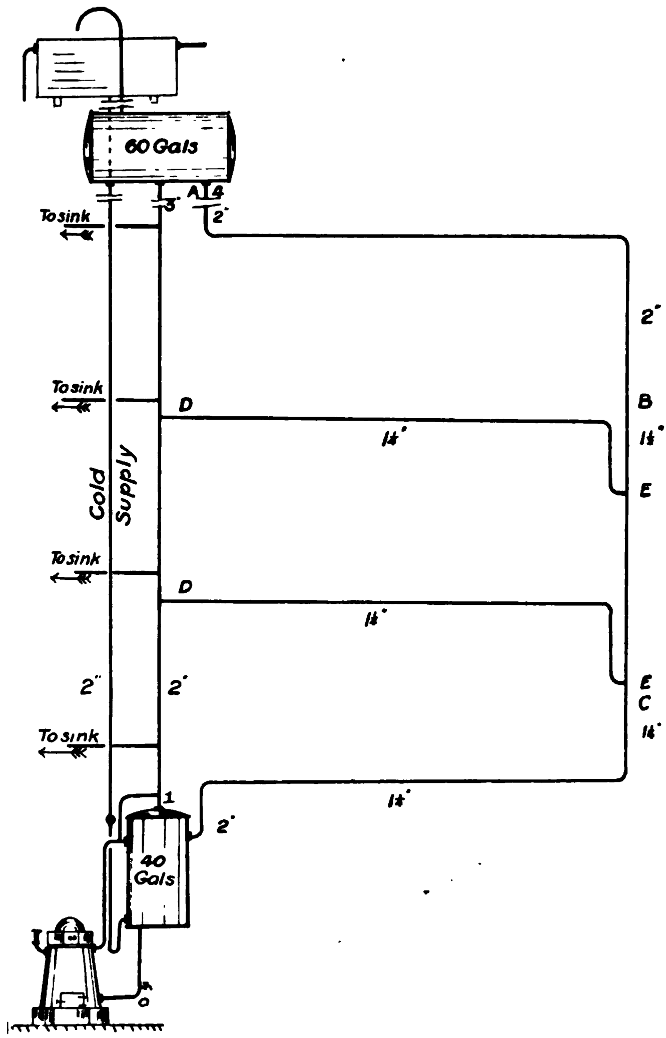


FIG. 127.—Hot-water Services for a Suite of Offices.

The cold supply pipe is 2 ins. in diameter, and the capacity of the tank is 40 galls. The latter quantity is sufficient if it

be required exclusively for feeding the hot-water apparatus, but if the water supply be on the intermittent principle, an additional cold storage tank will be necessary, or a larger hot-water feed tank must be provided. The temperature of the stored hot water need not exceed 180° F.

Hot-water services in flats and tenement houses require special treatment. The most satisfactory mode of supply consists of an entirely separate system for each suite of rooms.

In some instances, the systems installed in a block of tenements are all supplied through one cold-water service pipe from a tank fixed in the roof as shown in Fig. 128, but there is some risk of the cylinders on the higher floors being emptied when the cold supply fails and water is drawn freely from the apparatus on the lower floors.

To prevent this reflux, valves are provided in some instances, but the probable failure of such fittings has to be taken into account.

Fig. 129 shows a more satisfactory arrangement, which consists of separate installations for each flat.

This mode of supply is sometimes objected to on account of the comparatively slow delivery of hot water through the supply pipe A, owing to the smallness of the "head" of water in the tank B.

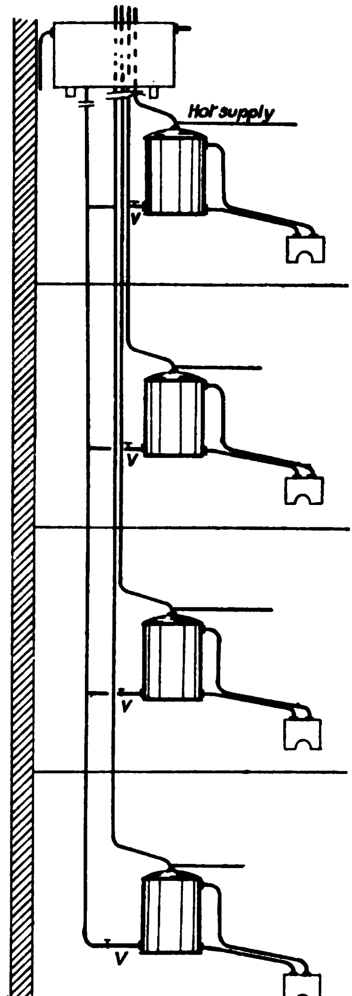


FIG. 128.—Defective System for Tenement Supplies.

This defect can be remedied by using a large diameter pipe,

$1\frac{1}{4}$ ins., for the cold service to the cylinder, and a comparatively large hot supply pipe between the cylinder and the fittings.

In the case of exceptionally low "heads" a reflux valve may be attached to the air pipe, so that air is prevented from entering the hot service pipe during a heavy delivery through the same. This will ensure a constant flow of hot water when the taps are opened.

The latter object can be achieved also by connecting the hot-water supply pipe to the cylinder at a point about 6 ins. below the top of the same, as shown at C.

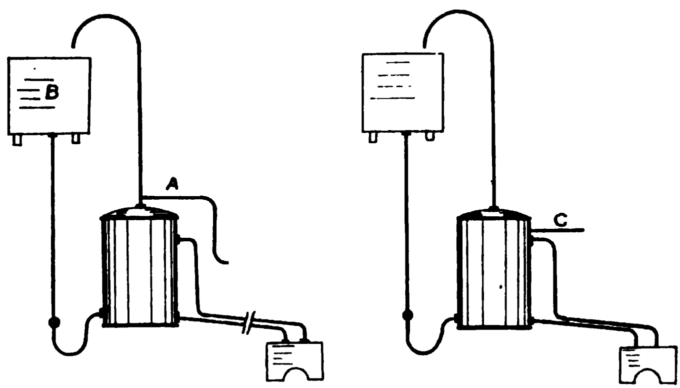


FIG. 129.—Satisfactory System for Tenement Supplies.

In certain districts the air pipes from the cylinders are connected to one vertical pipe, which is continued through the various floors, and terminated either on the roof or above the cold-water tank in the highest flat. There is no advantage in this arrangement; but if the free end of the air pipe becomes blocked, the contents of the upper cylinders will be siphoned through the cylinders on the lower floors.

The combination of the heating apparatus with the domestic hot-water services is often adopted in hospitals, banks, and similar buildings. Although this method is advocated on the score of economy as regards maintenance charges, the contention cannot be upheld in all cases. For large hospitals consisting of one or more blocks of buildings, the cost of control and maintenance is undoubtedly less if the combined

system be adopted, than would obtain in the case of a duplicate system; but for small hospitals that are warmed by either high- or low-pressure hot water, a separate system of hot-water services is advisable for the following reasons:—

1st. That the boiler capacity for the dual purpose will be considerably above the requirements of the domestic hot-water services during the summer-time; the result of this will be that the water will be almost constantly at or near to boiling-point temperature, thus causing a waste of fuel and subjecting the apparatus to unnecessary stresses.

2nd. If the water be "soft" or slightly acid, it will be discoloured by the iron which it removes from the pipes and fittings of the warming portion of the apparatus.

The latter disadvantage would occur only in the case of the low-pressure hot-water system where direct heating of the water is adopted in both parts of the apparatus.

If the high-pressure hot-water system be combined with the domestic hot-water service arrangement, indirect heating is resorted to for the latter purpose, and consequently it is not subject to the second disadvantage mentioned.

Such a combination cannot be recommended, as the maintenance of a steady temperature of the water in the high-pressure system is dependent upon even and frequent firing of the boiler; moreover, if arrangements are made to shut off the "warming" portion of the apparatus during hot weather, the boiler will be much too large for the domestic service portion.

Indirect heating is occasionally adopted in combined systems, but it proves unsatisfactory in most instances, owing to an insufficient area of heating surface being allowed between the two parts of the system.

The arrangement usually consists of a double cylinder, as shown in Fig. 130. The inner cylinder is connected directly to the boiler by flow and return pipes, or the latter may join the main-circulation pipes of the heating system.

If a large quantity of hot water is required each day, the heating surface of the inner cylinder will probably be insufficient for the purpose unless an abnormally large and costly double cylinder is adopted. The heating surface can be greatly increased by inserting a battery of 2-in. copper tubes of very light section, as shown in Fig. 131, in the place of the inner cylinder.

The upper and lower ends of the tubes are brazed into two circular distribution chambers. The lower chamber is connected to the flow and return pipes.

The latter pipes should be not less than 2 ins. diameter, and would be better if of 2½ ins. or 3 ins. diameter. The success of the apparatus mainly depends upon the rapidity of the circulation between the battery and the boiler; therefore the reduction of the velocity of flow by friction must be prevented as far as possible by the use of short circulation pipes of large diameter.

The latter pipes may be of cast or wrought iron between the boiler and the cylinder, but for soft or acid water the whole of the cylinder apparatus must be constructed of heavily tinned copper.

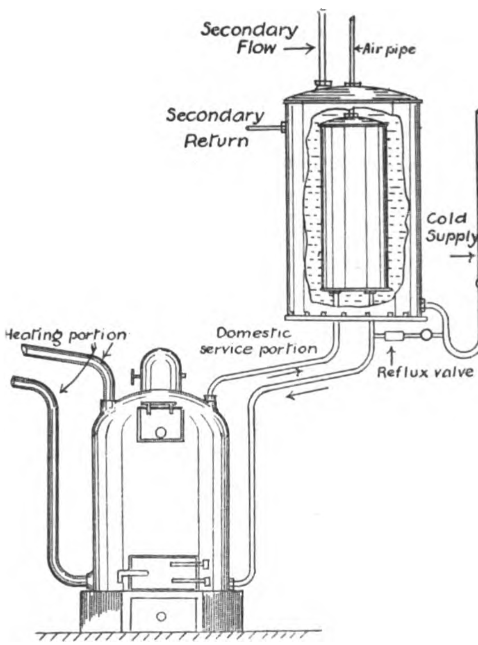


Fig. 130.—Double Cylinder System of Water Heating.

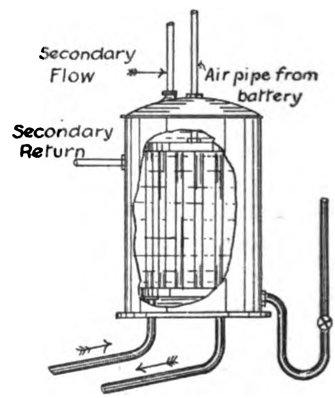


Fig. 131.—Cylinder with Battery of Tubes.

If the water supply is of a temporarily hard character, the cylinder and its parts can be formed of galvanised iron.

In this system hard water will not deposit lime carbonate, as the temperature of the water in the domestic service portion of the apparatus rarely exceeds 160° F.

If the warming of a hospital building is accomplished by

the use of low-pressure steam, the hot-water service can be connected to the same with economical results.

A Steam Heater or Calorifier is used for transmitting the heat from the steam to the water. The pressure of the steam in a low-pressure system rarely exceeds 5 lbs. per square inch —a pressure between 2 and 3 lbs. per square inch is generally used.

For a single hospital block the arrangement shown in Fig. 132 will prove satisfactory.

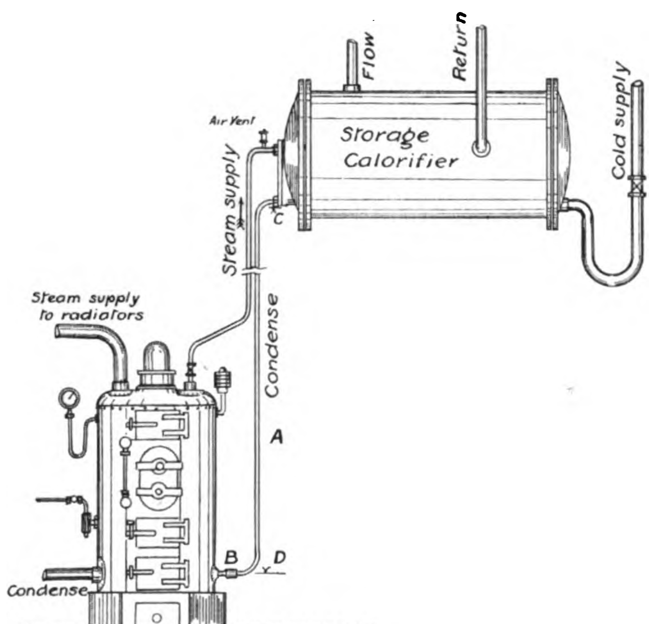


Fig. 132.—Storage Calorifier System, using Low-pressure Steam.

A calorifier of the storage type is connected to the steam boiler by means of a 1-in. diameter pipe. The condense is returned to the boiler by pipe A; a reflux valve being provided at B to prevent the water in the boiler from passing into the heating portion of the calorifier.

The latter trouble can be avoided by fixing the calorifier at a height of from 8 to 10 ft. above the boiler. If this is done, the condensed steam will form a column of water in the pipe A equal to a head, C D, which will be sufficient to overcome the

partial vacuum formed in lower part of the heater by the condensation of the steam. The steam tubes of the calorifier will thereby be kept free from condense water.

The question of providing a secondary circulation and a

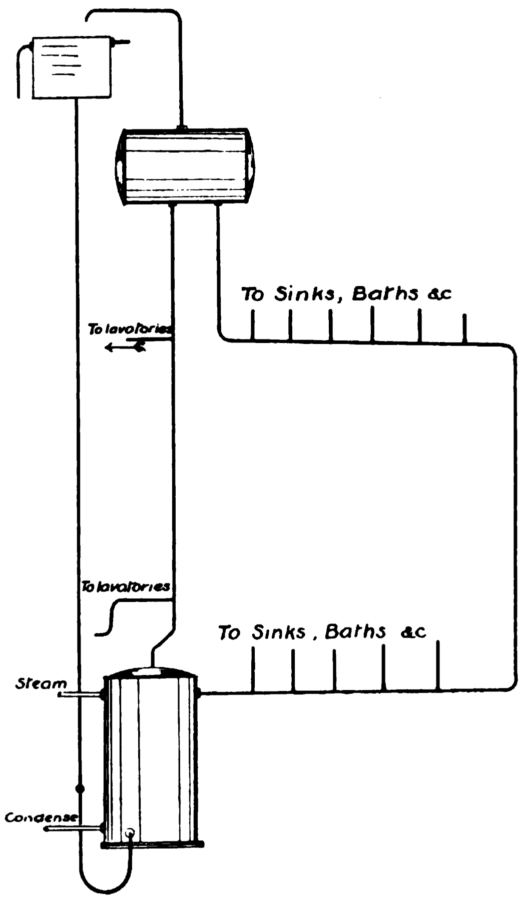


FIG. 133.—Cylinders with Steam Supply and Secondary Circulation.

reserve storage cylinder or tank will be decided by local conditions and requirements. In one-storey buildings a secondary circulation is not often necessary, unless the fittings are fixed in positions remote from each other, or are an appreciable distance from the calorifier.

For buildings of two or more storeys the provision of a reserve tank as shown in Fig. 133 is necessary.

Bath water in quantity is usually required simultaneously on all floors, and the diameters of the hot-water supply pipes must be large enough to ensure quick filling of the baths.

This mode of heating the domestic service water can also be adopted in the case of a group of buildings that are warmed by low-pressure steam supplied from a central heating station.

The sanitary fittings are generally situated at the ends of each building, whilst the work of the wards is administered from a group of rooms in the centre of each block.

The distance between the groups of sanitary fittings in each block will have to be taken into consideration. This factor has an economical bearing upon the question of installing one or more systems in each building. If the buildings are of considerable length it will be economical to provide separate systems for each group of fittings, but in the case of smaller buildings one system of domestic services for each building will be less costly to install and maintain.

Fig. 134 shows a sectional elevation of a domestic service suitable for a moderate-sized hospitable block. It is assumed that there are several blocks of buildings, and that they are warmed by low-pressure steam radiators. The steam is generated in a central station and supplied to each building through branches from a main conduit laid in brick trenches. The condense is conveyed through the pipe shown in dotted lines either to a vacuum pump or directly into the boiler.

The steam supplies to the calorifiers are taken from the main pipes as they enter the buildings (usually in the basements), and the condense is conveyed by dip pipes to the main condense conduit.

In addition to the storage calorifier fixed in each block, it will be advisable to provide a reserve cylinder or tank above each group of fittings. The flow pipe from the calorifier should be taken vertically into one of the hot storage tanks as at X. Branches from this pipe must have a gradual declination towards the hot storage tanks.

The branch marked No. 1 is of 2 ins. diameter. It acts as a flow pipe to the additional reserve tanks. The return pipes

are each $1\frac{1}{2}$ ins. diameter, and are connected to a pipe of 2 ins. diameter, which enters the calorifier as shown.

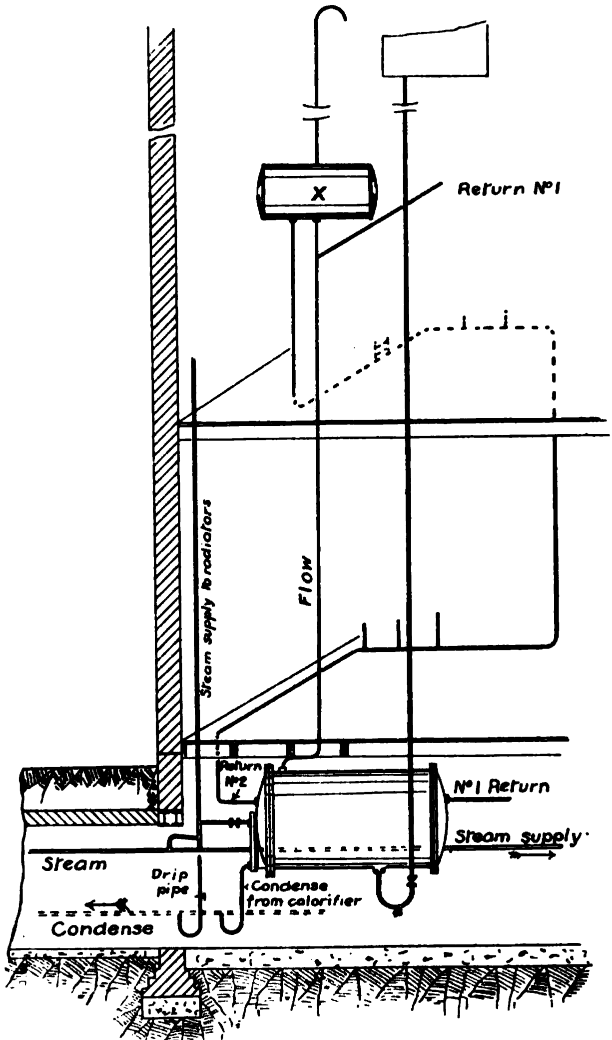


FIG. 184.—Cylinder and Tank System for Hospital.

The return No. 2 from the reserve vessel X passes through the first and ground floors, and is connected to the opposite side of the calorifier.

The main steam supply pipe must be of sufficient capacity to satisfy the maximum requirements of the dual system.

It is advisable to cover the pipes, cylinders, and tanks of the domestic services with a non-conductor, such as slag wool, to minimise the loss of heat by radiation.

The hot-water storage tanks that are fixed above each group of fittings provide a full delivery at all the draw-off taps.

During a heavy demand the water-level in these tanks will be lowered, as the flow through the inclined pipes will be insufficient to compensate the delivery or draw-off; the deficiency, however, is quickly made good when the demand ceases.

In districts possessing "hard" water supplies, the temporary portion of the hardness is usually sufficiently great to necessitate special treatment before the water is used for potable purposes. Although special apparatus to achieve this is usually installed in the case of hard-water supplies to mansions and large houses which have their own supplies, it is rarely used in smaller houses. Again, few waterworks authorities resort to treatment for the reduction of temporary hardness unless the latter is excessive.

Domestic hot-water systems using temporary hard water require special consideration. The carbonate of lime is slowly deposited when the temperature of the water approaches boiling-point, at which temperature the whole of the lime and magnesium carbonates are precipitated.

The precipitate, which is in a state of fine division, gradually accumulates and forms a hard scale on certain parts of the apparatus.

The scale accumulates most rapidly on the bottom and front plates of the boiler, thus necessitating provision being made in the design of the boiler which will permit of access to the interior for periodic removal of the scale.

A considerable quantity of the precipitate is carried by the water along the flow pipe; some is deposited *en route,* whilst the remainder enters the cylinder.

It is usually found that the return pipe has little or no deposit on its inner surface. This is due to the fact that the precipitate has sufficient time to settle in the cylinder and flow pipe before the water again enters the return pipe.

The boilers used in these systems are usually of cast- or wrought-iron. Such metals can be adopted with advantage, as the deposit of lime carbonate will form a protective coat on the surface of the iron and thus prevent corrosion. Again, wrought-iron can be hammered and chipped with impunity during the scaling process, without suffering material damage.

Copper boilers have not the same length of life when fixed under similar conditions of service.

The circulation pipes are best of steam-strength galvanised wrought-iron. Lead is not suitable, as the scale cannot be removed from pipes of lead without causing them permanent injury.

Provision must be made for readily detaching the circulation pipes in lengths that are convenient for handling. No elbows should be used on any part of the system, especially on the circulation pipes should this precaution be observed.

The cross-sectional areas of the latter pipes should be greater than those used in connection with soft water, to allow for the loss of capacity due to the accumulation of scale. The flow pipe is generally one size larger than the return pipe.

The frequency of the scaling operation will be governed entirely by local conditions. In some parts once per year will be sufficient, whilst in others it will be found necessary to remove the scale from three to four times per year.

Special Systems for preventing the precipitation of lime carbonate have been designed; but although they generally achieve this object, they possess other defects that more than counterbalance their advantages.

Fig. 135 shows a system in which a double boiler is used to prevent the water being raised to boiling-point temperature, thereby obviating deposit of lime carbonate.

The outer boiler is of large capacity, and is supplied with water from the flow pipe through the medium of the tank A. The pipe B permits air or steam to escape from the boiler C. The heat of the fire passes through the water in C to that contained in D, but the rate of transmission of heat under these conditions is so slow that it is almost impossible to obtain a satisfactory supply of hot water by this method, unless the boilers be made abnormally large.

It is claimed for this system that an explosion of the boilers cannot occur in the event of the circulation pipes becoming blocked, as the temperature of the water in D cannot be raised above boiling-point, also the boiler C is provided with a short length of pipe, B, which if blocked by ice would be released by the heat from the fire long before the pressure in C was sufficient to cause an explosion.

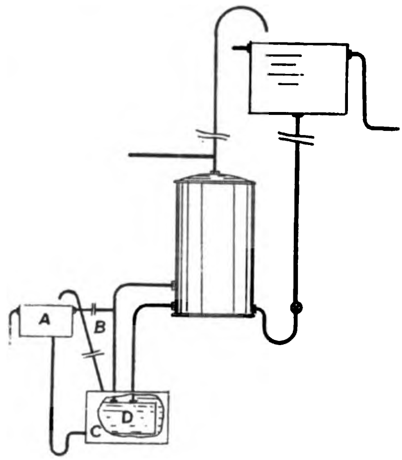


FIG. 135.—Double Boiler Arrangement.

The latter advantage is of doubtful importance, as the same object can be achieved by the use of a suitable type of safety valve.

The Pressure System of domestic hot-water service is not adopted in this country, but in America it is in general use. The usual separate cold-water supply tank is dispensed with and the cylinder is connected to the cold-water service pipe from the town's main.

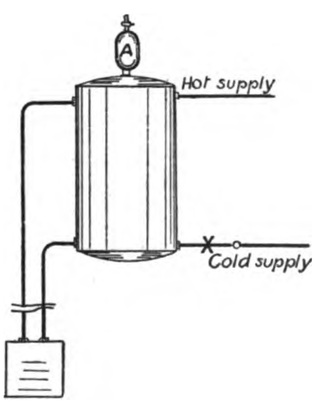


FIG. 136.—American System of High-pressure Hot-water Services.

Fig. 136 shows one type of this system. The circulation pipes are treated in the ordinary way as regards their connections with the boiler and cylinder. The latter vessel is made sufficiently strong to enable it to withstand a much greater pressure than that in the town's main.

The cold supply pipe is sometimes provided with a reflux valve, X, to prevent the hot water from passing into the cold-water main when the cylinder-content expands under the influence of heat; if a reflux valve be used,

an air-vessel, A, must be fixed to the top of the cylinder to provide accommodation for the increase of volume of the cylinder-content, otherwise there will be some risk of the cylinder bursting.

The air released from the water during warming accumulates in the air-vessel, and thereby keeps it charged with air.

It should be remembered that water expands to the extent of approximately 4·5 per cent. of its volume when its temperature is raised from 4° C. to 100° C.

The use of this system would not be permitted in this country, owing to the risk of water passing back into the town's main, and explosion or bursting of the cylinder. Moreover, the maintenance of the hot supply depends entirely upon the pressure and volume of the water in the town's main. When the supply in the latter is shut off, the system immediately fails.

Domestic hot-water services in connection with large public buildings or institutions, especially where the latter consist of groups or blocks of separate buildings, require special treatment.

In most cases a boiler is installed for generating steam for cooking and for power purposes, such as lighting and laundry work, etc. The question therefore arises as to the advisability of adopting a centralised method of warming and distributing the water for domestic use, whereby all the buildings receive supplies from a central heating station, or the alternative provided by the decentralised method, in which the buildings are separately supplied by a small system installed in each of them.

In the case of an institution consisting of one large building, the centralised method is undoubtedly the best; it offers no difficult features either in design or construction; moreover, it is economical to install and maintain. But where the institution is made up of a number of separate buildings situated some distance apart, various additional constructional details are discovered which require careful consideration.

Under such conditions it will generally be found that the circulation of the water by the gravitation or natural method will be very sluggish, owing to the excessive length of the circulation pipes, the loss of heat by radiation from the pipe

surfaces, and the smallness of the "circulating head," which is responsible for the movement of the water in the circuit.

The latter will be no greater than that of any compact system fixed in a building of a similar height, and it will in general prove insufficient in the former case.

With regard to loss of heat by radiation, this will occur to a limited extent even where the pipes are protected by a non-conductor of heat. In the rising part of the circulating main it will operate against the velocity of flow by reducing the "circulating head"; whereas, occurring in the descending or return pipe, it will tend to accelerate the rate of flow.

In general, the centralised method is not adopted in the case of systems used exclusively for the supply of hot water for domestic purposes.

Combined Warming and Domestic Service Systems have been adopted during recent years in connection with groups of buildings.

The main feature of these schemes is, that the control of all hot-water supplies for warming and domestic use is placed in charge of a competent person and can be exercised in one central station. The warming arrangements are of the "low-pressure hot-water" type, and, being on the same principle as the domestic hot-water services, there is no special constructional difficulty experienced in combining the two systems.

Forced circulation is invariably resorted to in these cases. The natural movement of the water in the pipe circuit by convection currents cannot be relied upon for several reasons, the chief of which is the insufficiency of the available "circulating head" to cause a requisite velocity of flow, and to prevent the difference of temperature in the flow and return pipes exceeding 20° F. where these pipes join the calorifier.

The appliances used for forcing the water through the circuit are:—

The "centrifugal" pump and the "ram" or "plunger" pump.

The former works at a high velocity and maintains a steady flow, whereas the latter, unless it be of the double-action type, tends to produce an intermittent flow; moreover, an air-vessel is necessary on the delivery side of the pump to provide

an air-cushion for diffusing the increase of pressure which occurs at each effective stroke of the piston.

In a combined system one or more calorifiers are invariably used for warming the water. Where the demand fluctuates, it is advisable to install at the least two heaters, or the steam tubes in one large heater may be grouped and controlled in sections, one or more of which can be brought into or cut out of action to accommodate the requirements of each day.

The steam is generally supplied at a pressure of from 20 to 30 lbs. per square inch; higher pressures may be used with advantage, but the difference in pressure must be taken into account when determining the required area of the steam tubes.

If exhaust steam in appreciable quantities be available from engines, a special calorifier should be fixed to utilise the latent heat of the steam. It should be remembered that 1 lb. of steam at 212° F. when condensed to water at the same temperature, liberates 966 British Thermal Units. One B.Th.U. will raise the temperature of 1 lb. of water from 32° F. to 33° F.

∴ 966 B.Th.U. will raise the temperature of 966 lbs. of water from 32° F. to 33° F.

Although it is economical to use exhaust steam, it cannot be relied upon to perform the whole of the work of heating the water for warming the building and for domestic services. Usually it is only available during a portion of each day, it is therefore essential to provide an additional calorifier served with steam under pressure, to supplement the one using exhaust steam.

The condense pipe of the latter is generally connected to a vacuum pump, whereas the former invariably exhausts into a steam trap; the condense in both cases being conveyed to a "hot well," from which it is pumped back again into the boiler.

The cylinder oil which invariably accompanies exhaust steam is detrimental to the efficient working of steam boilers. Exhaust steam is passed through grease extractors to separate the grease and oil, or the condense water is so treated before it is returned to the boiler.

The calorifiers are connected to the circulating mains in such a manner that they can be used collectively or individu-

ally. Thus in the event of defects occurring in any one calorifier, they can be repaired without interfering materially with the working of the system.

The Pipe Arrangements consist of circulating mains of large diameter, which convey the hot water from the calorifiers through the various buildings, and finally return the same to the pump, which forces it again through the calorifiers, thus maintaining a constant flow in the circulating mains by mechanical means.

The latter pipes are laid at regular inclinations in specially constructed trenches or subways which link up the different buildings, and are continued through a convenient portion of the basement of each building. One or more subsidiary mains are connected with the circulating mains to provide hot-water supplies to sanitary fittings and radiators. The circulation of the hot water in the subsidiary mains, although aided by the mechanical effort of the pump, depends principally upon the natural laws which produce convection currents.

The domestic hot-water services are usually catered for by a separate set of subsidiary mains. These are laid so as to include in the route which they traverse the positions of the various fittings requiring hot-water supplies.

The escape of air released from the water during its passage throught he pipes is provided for at all radiators, also, the domestic service circuit is generally arranged so that a branch supply occurs at its highest point, through which the air escapes on opening a tap.

In general, the circulating mains may be arranged in two ways. One consists of a single pipe circuit commencing at the calorifiers and terminating at the circulating pump, whilst the other has a duplicate set of circulating mains.

In the latter system, the combined capacity of the two mains is approximately equal to the capacity of the single pipe used in the former system.

The central heating station generally occupies a convenient position from which the hot-water supplies can be distributed with a minimum length of pipe and loss of heat. Although the calorifiers are usually placed in the basement storey of the building, it is not essential that they be fixed at a lower level than the lowest point of the circulating mains, but provision

must be made for the escape of air from the high part of the main where it leaves the calorifier.

Fig. 137 shows the plan of a group of hospital buildings in which the heating and domestic hot-water services are combined, forced circulation being adopted. The central station S is situated below the cook-house and is also near the steam boilers. The pump P forces the water through the three calorifiers C and into the circulating main M. The latter pipe has a gradual fall from this point throughout its entire

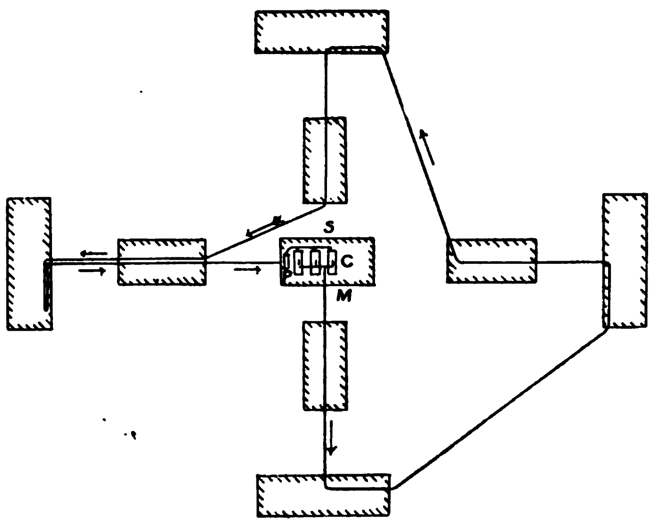


Fig. 137.—Plan of Circulating Mains for Group of Buildings.

route, and finally reaches the pump P, which is the lowest point of the circulation.

The main pipe line is housed as far as possible in the basements of the buildings; between the buildings special subways are constructed, usually of bricks. In many instances these are made large enough to accommodate the gas- and water-mains and the electric cables, also to provide free access for inspection and repairs.

The subsidiary mains are connected at convenient points to the circulating mains. The flow pipes are invariably taken from the top of the mains, whilst the return pipes may enter the side or the bottom of the same.

Fig. 138 shows a vertical section through one of the buildings, which illustrates one mode of pipe arrangement.

It will be observed that the domestic services are independent of the hot-water services to the radiators. Usually,

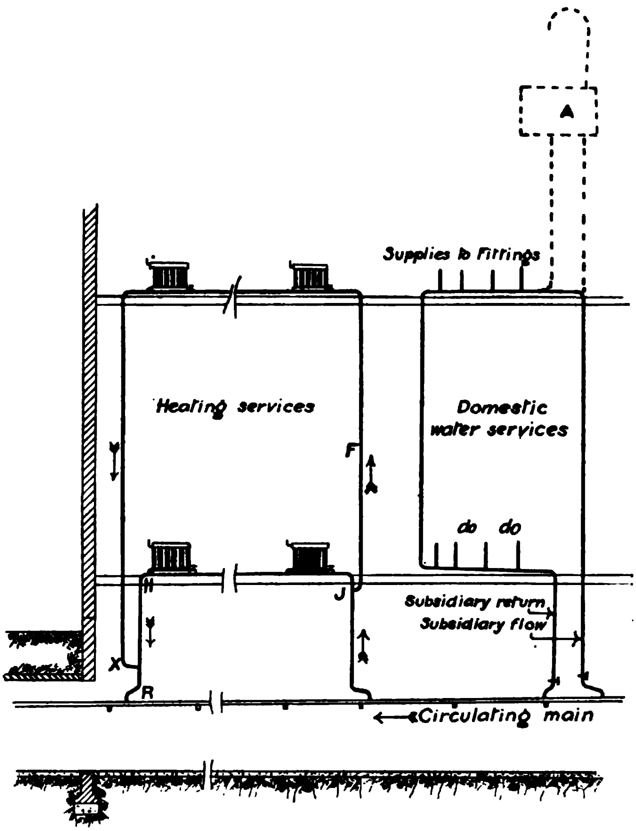


FIG. 138.—Vertical Section showing Radiator, etc., Connections.

separate subsidiary mains are provided for each side of a building.

The question of providing a hot storage tank at A requires consideration. If the head of water be reasonably high, and the capacity of the domestic subsidiary mains is sufficiently large, a tank will not be necessary. The diameter of the latter mains should be not less than 1½ ins., and if they are of considerable length 2-in. pipes should be used.

The circulation in these pipes can be increased by the use of special connections, which divert a portion of the stream of water from the principal mains into the subsidiary mains. Where the latter pipes are of abnormal length and are laid at a slight inclination, as in the case of one-storey buildings, the use of special connections is advisable, otherwise the flow will be sluggish.

The radiator supplies may be arranged in several ways. The mode indicated in the diagram is similar to the "single pipe system." The flow pipe F rises to the ground floor and is continued with a slight declination past the various radiators, and finally descends, and is connected to the circulating main at R. A branch from the pipe F supplies the radiators on the first floor, the return from which joins that from the radiators on the ground floor at the point X. The column of cooled water in H R ensures the circulation of water through the pipe H J.

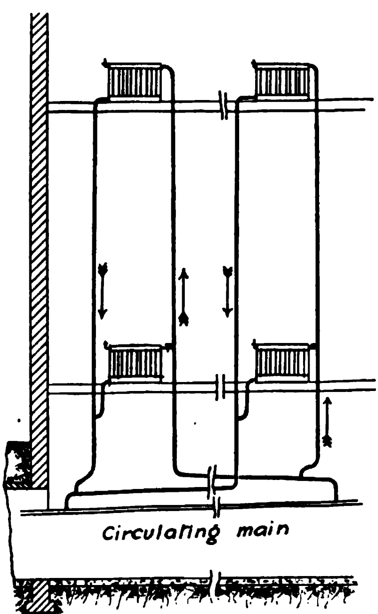


Fig. 139.—Vertical Section showing Radiator, etc., Connections.

Another method which may be adopted for supplying the radiators is shown in Fig. 139. In this example separate risers or vertical flow pipes are provided for each tier of radiators. The return pipes are also run vertically to a subsidiary return in the basement, which is eventually connected to the circulating main.

Air pipes or automatic air release valves are fixed on the radiators; also, the latter are controlled by cocks or valves.

All the subsidiary mains in a large scheme should be provided with full-way stopcocks fixed as near to the circulating main as possible, so that repairs or alterations can be undertaken without disturbing other parts of the system.

The chief disadvantage of the single pipe circuit is the risk of the whole of the system being rendered inoperative should a defect occur in the circulating main. Control cocks are arranged at intervals on the circulating main, so that any section of the same may be repaired without necessitating the emptying of the whole of the system.

The "duplicate" or "two-pipe" system consists of two instead of one principal main. By-passes controlled by stopcocks are provided at certain points on the circuit, which permit of intercommunication between the two pipes being established in the event of failure of one or more sections.

Fig. 140 shows a line diagram which illustrates the

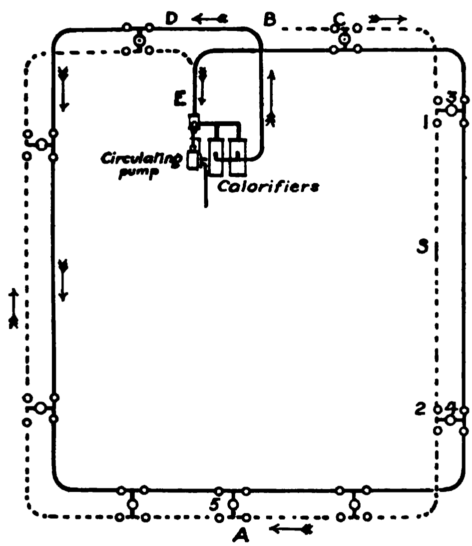


Fig. 140.—Diagram of Duplicated Circulating Mains.

principle of this system. The leading main or flow pipe divides at the point B, which is the lowest part of the pipe system, the highest being at A. The two flow pipes C and D complete the circuit, and eventually are connected to the pump by means of the pipe E.

Generally, the pipes are fixed side by side throughout the route. It will be observed that the flow of water in the two pipes is in opposite directions, as indicated by the arrows.

If a defect occurs in any part of the main circuit, the

section which it affects can be disconnected from the remainder of the system whilst the defect is repaired. All subsidiary mains for domestic services that are fed from this portion will be supplied through the connection with the second pipe. If repairs are required in the section marked S, the valves 1 and 2 are closed, and the by-pass valves 3, 4, and 5 are opened, thereby providing for a free circulation of water through the remaining portions of the circuit.

The subsidiary mains have one pipe connected to each of the circulating mains. These pipes may also have cross connections with both mains, so that the cutting out from the circuit of one section will not put them out of action.

Fig. 141 shows duplicate connections of the flow and return pipes to a group of radiators. Under normal conditions the valves 1 and 2 are open. If the pipe A is disconnected for repair purposes, the circulation in the pipes C and D can be maintained through the valves 1 and 3, likewise through those marked 2 and 4, when the pipe B is out of action.

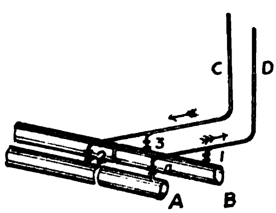


FIG. 141.—Duplicated Connections of Subsidiary Mains.

Although this system is more costly than the single pipe method, it is much more reliable.

In large installations the circulating mains are usually of cast-iron, whilst the subsidiary mains and all connections with the same are either of light section copper pipe, or water-strength galvanised wrought-iron pipe. The latter are not suitable where soft or acid water is carried. Under such conditions the pipes would be gradually corroded, owing to a mild galvanic action which would develop.

In smaller undertakings where forced circulation is adopted, especially if the system be used exclusively for domestic hot-water services, the whole of the pipes should be of light section copper heavily tinned inside and out if they are intended for use with soft or acid waters. Copper pipes from 2 to 3 ins. diameter 14 B.W.G. thickness can be used, and for smaller sizes 16 B.W.G. will be ample.

The calorifiers used are generally those of the storage type. As previously mentioned, it is advisable to have them in

duplicate; also, where exhaust steam is available, an additional calorifier should be fixed to deal with the same.

Thermometers should be provided on the flow and return pipes of each calorifier, to enable the attendant to control the temperature of the circulating water.

Fig. 142 shows an arrangement of heaters and pumps suitable for a forced circulation system.

The storage calorifiers are in duplicate, as also are the circulating pumps.

The flow pipes from the calorifiers join one main pipe, which is continued in one or more directions and eventually is connected to the return pipe. The latter is in duplicate and is attached to the suction pipes of the pumps. The water is forced through the exhaust calorifier into the storage calorifiers, or, if no exhaust steam is available the by-pass valves are opened, and the water passes directly into the latter vessels.

The exhaust calorifier is of the heater type. In consequence of the steam tubes which it contains being closely compacted, also the appreciable velocity at which the water is forced through the heater, rapid condensation of the steam occurs.

The pipes and valves are so arranged that complete duplication of all parts is obtained. Each pump may be used along with one or both of the storage calorifiers, the exhaust steam calorifier being included or not according to local conditions.

There is a difference of opinion as to the type of pump to adopt. The ram or plunger pump is most commonly used, but it is objectionable on account of the noise which it produces at each change of direction of the stroke. In buildings such as hospitals and infirmaries, where absolute quietness is a desideratum, the clanging noise is particularly unpleasant, occurring as it does with monotonous regularity throughout each day. The sound is carried by the pipes through the whole of the circuit.

The advantages of the ram pump for this purpose consist chiefly in its power to maintain a definite flow of water under all conditions; also, the slowness of the movements of its parts reduces wear and tear, and consequently maintenance charges, to a minimum. Moreover, it is compact, and does not require a separate engine to work it.

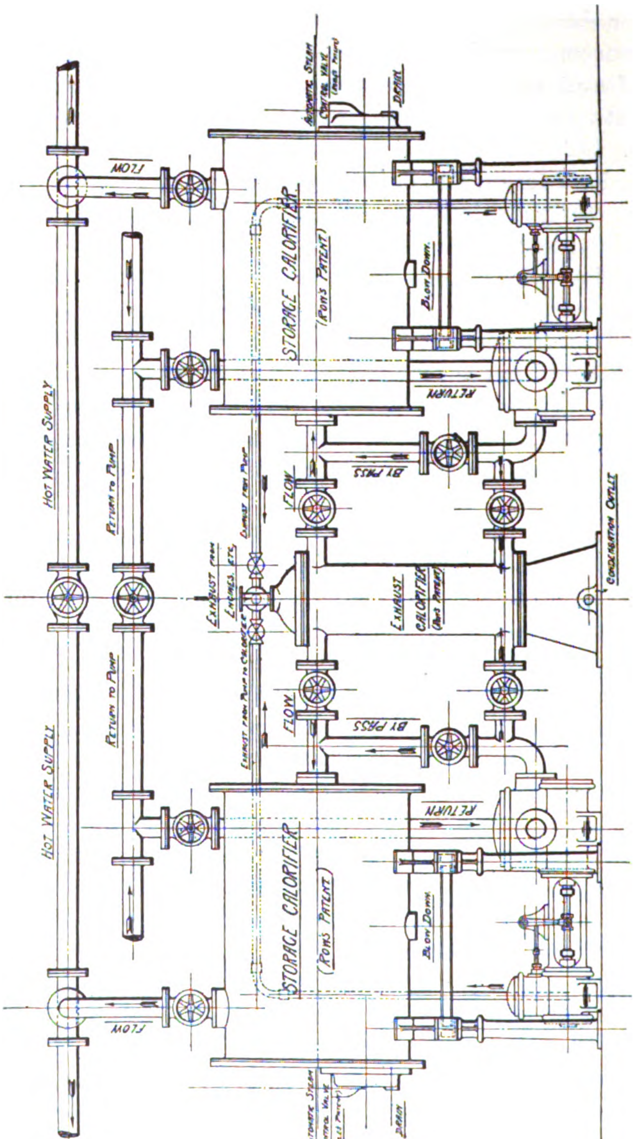


Fig. 142.—Calorifiers and Circulating Pumps.

The diameter of the pump barrel is usually equal to that of the circulating main. Air-vessels are generally used on the suction and delivery pipes of ram pumps.

The centrifugal pump does not produce an appreciable amount of noise when working. Although the wheel revolves at a comparatively high speed, smooth and noiseless running is attained if the machine receives reasonable attention, owing to the entire absence of reciprocating parts. An electric motor is most suitable for rotating the pump.

The chief disadvantage is the risk of air accumulating in the wheel casing, when the wheel would revolve at a high speed, and churn up the air without doing effective work.

The velocity of flow through the circulating mains should

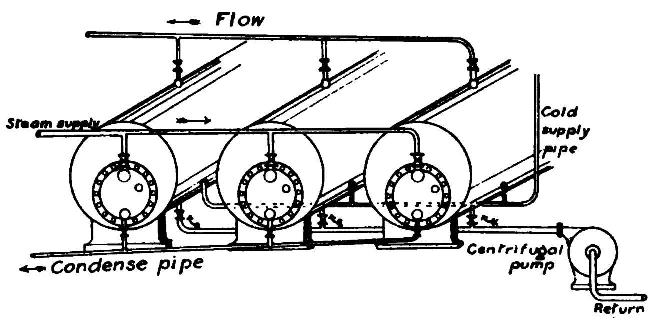


FIG. 143.—Calorifiers with Centrifugal Circulating Pumps.

be kept below the "critical speed" to minimise the friction losses. A velocity of from ·25 to ·5 ft. per second will generally prove sufficient.

The cold supply pipe and storage cistern should be of sufficient capacity to meet the maximum demand for which the system is liable. The supply pipe is connected to the bottom of each calorifier by means of branch pipes, as shown in dotted lines in Fig. 143. Each branch is controlled by a cock fixed near to the calorifier.

The heaters are of the storage pattern. The steam supply may be controlled by hand, or an automatic attachment can be fixed to each calorifier to regulate the supply of steam according to requirements.

The advantages of the central combined mode are:—

1*st*. All the heating and domestic hot-water supplies are

controlled from one centre, thus involving less supervision than in the separate or decentralised mode.

2nd. A definite flow of hot water is maintained, and the temperature of the same does not fluctuate appreciably throughout each day.

3rd. The heating arrangements may be fixed in any convenient position, irrespective of the levels of the pipe mains.

4th. Exhaust steam is generally available in such buildings, and may be economically employed for heating the water.

The disadvantages are:—

1st. The cost of the installation usually is greater than in the separate mode, owing to additional structural work such as brick culverts, trenches, or subways, and long lengths of pipes.

2nd. If one of the circulating mains in the single pipe system fails, the remainder of the scheme is put out of action.

3rd. In districts supplied with soft water, the cast- or wrought-iron circulating mains are corroded. The iron rust is carried into the smaller pipes, and is often responsible for stoppages of the same. Moreover, the domestic hot water is discoloured in some cases and rendered unfit for personal use.

Although copper pipes are invariably used for the subsidiary connections, they do not eliminate this disadvantage.

4th. In the case of the use of temporary hard water, the pipes will have their capacities gradually reduced by the deposit of carbonate of lime on their interior surfaces, unless the water be softened previous to use, or its temperature kept below 180° F.

5th. A considerable amount of heat is lost from the circulating mains, notwithstanding the fact that they are invariably covered with a poor conductor of heat.

CHAPTER IX

CALORIFIERS: THEIR CONSTRUCTION AND USE—HEATING SURFACES OF STEAM PIPES USED IN SAME—LIVE STEAM AND EXHAUST STEAM SUPPLIES — CONDENSE — STEAM TRAPS FOR THE CONDENSE.

THE term calorifier can be applied generally to any apparatus that is intended for raising the temperature of water by the use of steam, but the term is usually confined to appliances that are provided with one or more sets of steam tubes which keep the water and the steam from actual contact with each other.

The simplest form of calorifier consists of a coil of pipe fixed inside a cylinder or tank, as shown in Fig. 144. The length of the pipe will be governed by the requirements of fittings to be supplied with hot water.

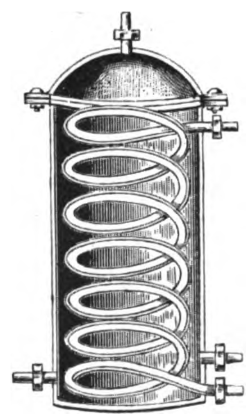


FIG. 144.—Steam Coil in Cylinder.

This form is not very efficient. In many cases the excessive length of the steam tube forming the coil, prevents the whole of its surface being effectively used. Condensation goes on rapidly in the upper part of the tube, thus causing a constant drenching of the interior surface of the lower portion, whilst the condense is draining towards the outlet. The stream of water prevents effective contact of the steam and the pipe surface, and in consequence the flow of heat is retarded. A series of coils of short length will give much more satisfactory results.

The modern forms of calorifiers are of two principal types—

1. The heater type.
2. The storage type.

The former consists of a cylindrically-shaped vessel containing a large number of steam tubes, which are so closely packed that the water capacity of the heater is comparatively small.

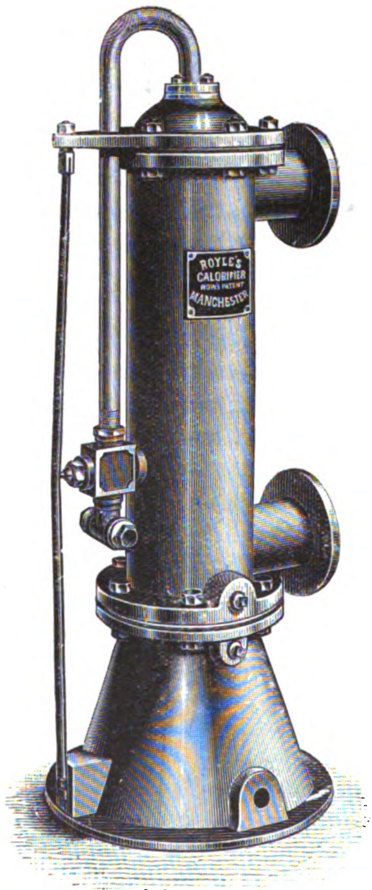


Fig. 145.—Vertical Type of Calorifier.

The vertical form shown in Fig. 145 is made of either cast-iron or copper. Copper is most suitable for use with soft or acid water, but cast-iron can be adopted where hard water is supplied.

The dome-shaped upper end forms a steam box from which the steam is distributed to the tubes. These are fixed vertically through the cylinder, and enter a condense chamber in the lower part of the heater. The condense is conducted from this point to a steam trap, or is otherwise dealt with.

The steam passes through a valve of the automatic type, which regulates the supply according to requirements.

The flow pipe is connected to the top, and the return pipe enters the bottom of the calorifier.

Where there is not sufficient head room to allow a vertical heater to be fixed, one of the horizontal kind, as shown in Fig. 146, can be used.

The steam tubes are connected to a chamber which is in turn attached to the dome-shaped flanged end. They occupy

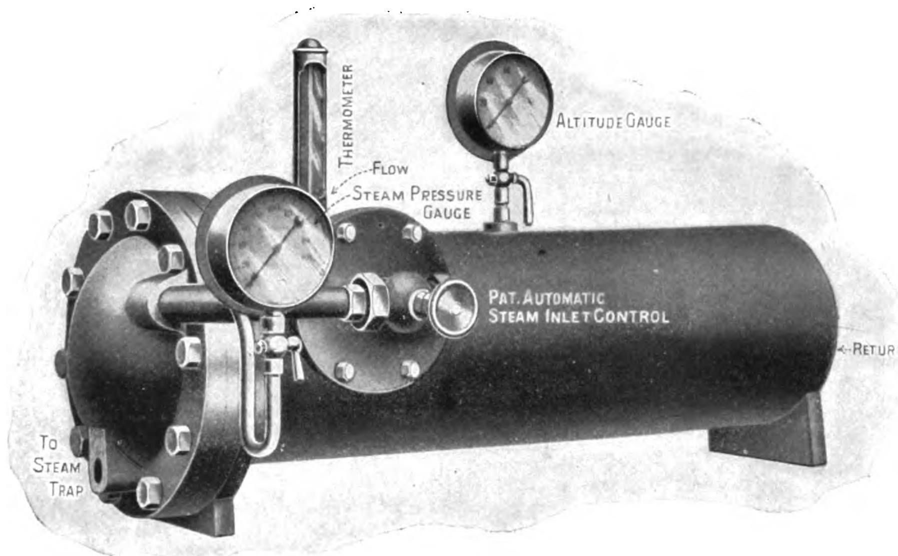


Fig. 146 —Berryman Horizontal Calorifier.

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the full length of the cylinder, and are returned to the condense chamber with a slight inclination.

A gauge is attached for recording the steam pressures.

A thermometer attached to the flow pipe indicates the temperature of the water leaving the calorifier. Also, a pressure gauge is fixed to the shell of the apparatus to indicate the head of water under which it is working.

The vertical form of calorifier should be used where possible in preference to the horizontal type. When the maximum duty is required of the latter, the horizontal steam tubes cannot drain away the condense as quickly as those in the former type, which are fixed vertically. A comparatively large portion of the invert of the tubes is covered with a stream of condense water during periods of rapid condensation, and in consequence the total amount of heat transmitted in unit time is reduced.

The "heater type" of calorifier is used in connection with the circulation of low-pressure hot water for warming buildings; also where it is advisable to fix the calorifier near to the boiler, and store the hot water for domestic services some distance from the same in a remote part of the building.

If the demand for hot water be fairly constant throughout each day, the heater type may be connected to a cylinder, and a satisfactory service thereby maintained; moreover, the calorifiers may be duplicated and connected on opposite sides to the cylinder. The additional heater can be requisitioned during a period of excessive demand; also, it acts as a stand-by when repairs are necessary to the service calorifier. For connecting to existing systems it proves efficient and economical.

In districts supplied with temporarily hard water, a heater should be used which will retain its efficiency for a reasonable period, and which can be readily inspected and cleaned.

The lime carbonate gradually accumulates on the outer surface of the tube, and tends to retard the rate of heat transmission from the steam to the water. Again, in certain cases the scale adheres tenaciously to the tube, and is only removed with difficulty.

Under these conditions additional heating surface is required; also, where one calorifier only is fixed, inconvenience and delay are minimised by having a duplicate nest or battery

of steam tubes, which may be inserted to replace those removed for scaling operations.

Fig. 147 shows a view of a special calorifier for this purpose. The rectangular door provides for access to the inner portion.

The tubes used in this pattern are of the indented type referred to later. It is claimed for them that they are self-scaling, owing to their irregular surfaces. This action is probably due to the several different directions in which the forces of expansion and contraction act.

Fig. 148 shows a cylinder to which a "heater" type of calorifier is directly connected. The various parts of the vessel that are in contact with water are of either copper or gun-metal, and in consequence can be used in districts supplied with soft water.

Storage calorifiers consist of one or more batteries of tubes fixed inside a cylinder. The capacities of the cylinder and the heating surface of the tubes should be equal to the requirements of a heavy and sustained demand.

This type of apparatus is suitable for use in large institutions where the demand fluctuates considerably; also where the warming and domestic hot-water services are combined.

Fig. 149 shows a vertical pattern of this type of heater, which can be obtained in sizes to suit any requirements up to 50,000 gallons of water per hour, heated from 50° F. to 200° F.

The flow pipe is attached to the top of the casing, and the return pipe enters near to the bottom. The steam supply is led into the chamber at the base, and is controlled automatically by means of a lever and rod arrangement.

Fig. 150 shows a horizontal storage calorifier, in which batteries of steam tubes are placed. The latter are attached to the large disc, and are inclined to allow of quick clearance of the condense, which is returned to the lower part of the disc and conveyed to a steam trap or to a vacuum pump.

The ease with which the whole of the batteries of steam tubes are detached and replaced by releasing the disc C, which really forms the outer face of the steam chamber, is a great advantage. Inspection and cleansing are facilitated, thereby preventing delay and inconvenience.

Automatic control of the steam supplied to a calorifier

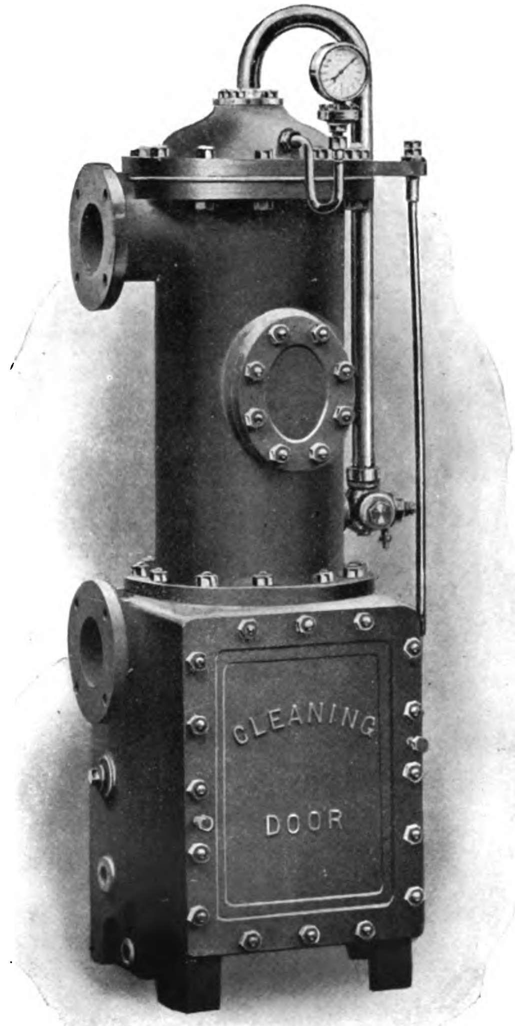

Fig. 147.—Royle's Calorifier for Hard Water.

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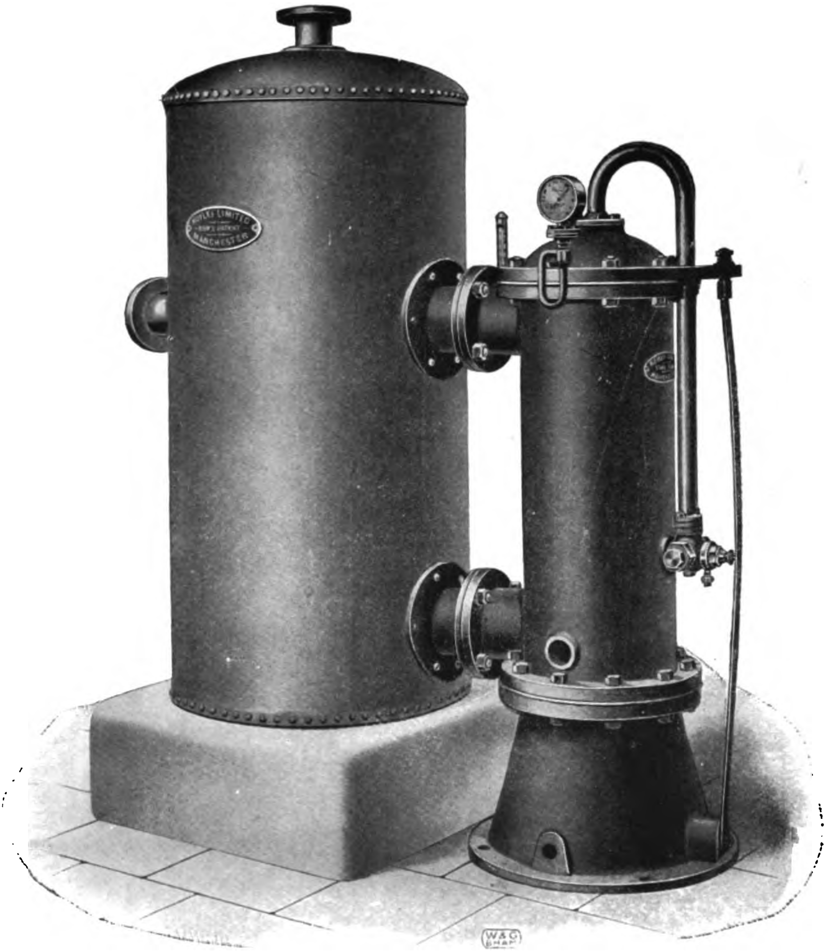

Fig. 148.—Royle's Calorifier attached to Cylinder.

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is useful to some extent in adjusting the supply of steam to meet the varying requirements.

Where the control depends entirely upon the manipulation of valves by an attendant, there is some risk of overheating of the water occurring, with consequent loss of heat and undue stressing of the various parts of the apparatus.

It must be clearly understood that automatic steam control devices are not absolutely reliable. They require periodic attention and adjustment, and cannot be relied upon to work efficiently and continuously under a range of temperature less than from 15° to 20° F. The better types of these devices,

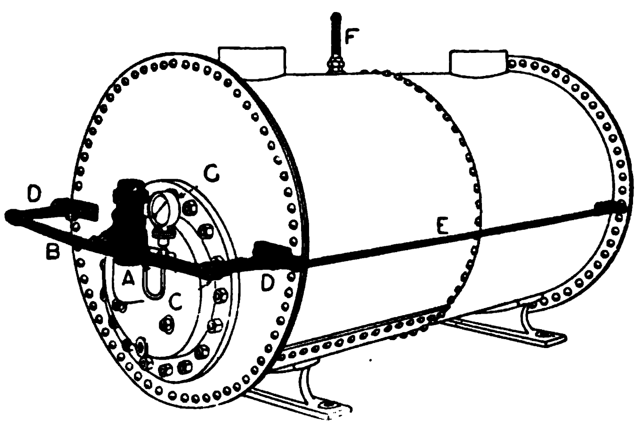

Fig. 150.—Royle's Auto Steam Control attached to Storage Calorifier.

however, undoubtedly exercise a measure of control that is conducive to economy and efficiency to a degree which could not be achieved by the intermittent attention of a caretaker.

The principle embodied in most of these appliances is based upon the effect of the expansion and contraction of metals. The forces available from this source are applied in the closing and opening of a special valve fixed on the steam supply pipe.

Fig. 150 shows one form of steam control as applied to a horizontal storage calorifier.

The steel rod E is in duplicate, *i.e.*, there is one on each side of the apparatus, and one end of each rod is securely attached to the rear part of the cylinder; the opposite ends are connected to two bell cranks D, which operate the steel band

B. The latter is arc shaped and its centre is in contact with the spindle of the valve A. Lock nuts are provided at one end of the steel band or bow string for regulating the tension necessary for closing the valve at a desired temperature.

The "control" is adjusted by first releasing the regulating nuts and allowing the water in the calorifier to be heated to the desired temperature—say, 180° F. The nuts are then tightened so that the band B is under sufficient tension to just close the valve A.

When the temperature of the water in the calorifier is reduced, the cylinder contracts, whilst the lengths of the rods E and the band B remain fairly constant, as they are not appreciably affected by changes of temperature in the calorifier. The band B becomes slack, and steam is admitted through the valve A to the tubes.

With an increase of the temperature of the water, the cylinder expands and puts the rods E in tension, and they in turn transmit the movement through the cranks to the band B.

Another type of automatic control, which is called a thermostatic valve, consists of a tube of mercury, M, inserted in the side of the calorifier (Fig. 151). A tube, T, of small bore communicates with a two-way valve, V. A tube of $\frac{1}{4}$ in. or $\frac{3}{8}$ in. diameter conveys a quantity of cold water from the cold supply pipe P through the valve V to a diaphragm valve, D. The latter is counterbalanced by means of a spring, and actuates a valve on the steam supply pipe. When the thermostat is adjusted for a given temperature, and the water in the calorifier is cooled below that point, the mercury contracts, the valve V opens and allows water to pass to the diaphragm D. The latter is depressed and opens the steam valve which admits steam to the calorifier.

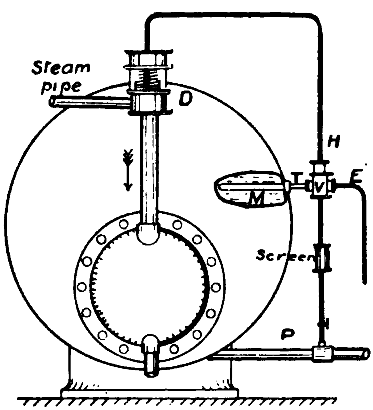

Fig. 151.—Thermostatic Valve.

The mercury again expands with the increase of the temperature of the water, the valve V, which is double-acting, closes the aperture leading to pipe H, and opens that in connection with the exhaust pipe E. The balance spring in the valve D slowly forces the water away from the diaphragm and closes the steam valve.

This thermostatic valve can be adjusted for any temperature.

The arrangements for dealing with condense water require some consideration. If the steam be supplied under pressure, the condense is led into a steam trap, but in the case of exhaust steam, or supplies at atmospheric pressure, the condense conduits may be connected to a vacuum pump.

The condense exit should never be open to the atmosphere. Under such conditions a waste of steam would occur; moreover, the water, which by an organised system of pipes can be utilised for boiler supply purposes, would also be wasted. The temperature of the condense as it leaves the steam trap is rarely less than 180° F. A useful amount of heat is conserved by returning it to the hot well for use in the boilers.

Steam Traps are of two principal types. One is operated by the expansion and contraction of two different metals working in conjunction with each other, or by means of an elastic loop, arc, or band of metal enclosed in a suitably constructed chamber.

The second type consists of a float arrangement enclosed in a cast-iron box. The raising or lowering of the float opens or closes the condense valve.

Fig. 152 shows a section of one of the former type of trap. The body A is made of gunmetal and the band B of steel. When condense water enters the body of the trap, the band B is relaxed, the valve C opens, and allows the water to pass through the outlet E. Immediately the gunmetal body A receives steam, it expands to a greater extent than the band B; thus the latter is put in tension, thereby closing the valve C.

The band is adjusted by means of the nut attached to one end of the same. The screwed bush D, which contains the valve C, is detachable.

Steam traps belonging to this class are not as reliable as those that are operated by means of a float arrangement.

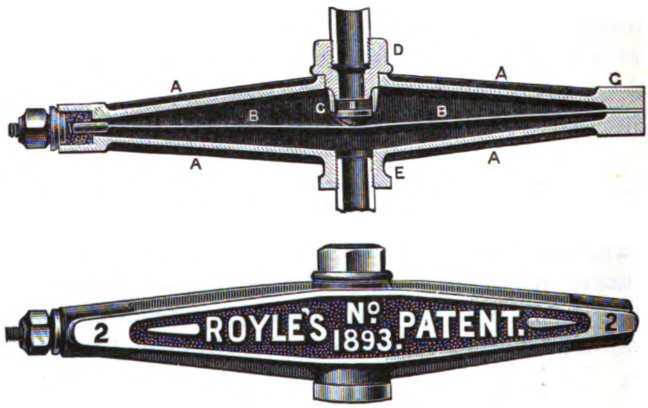

Fig. 152.—"Expansion" Steam Trap.

Fig. 153 shows a section through one of the latter class. The condense pipe is connected to the union O, and the trap is filled with water. The valve E possesses a small aperture that is left open when the valve closes. The water of condensation enters the trap through E, and passes in the direction indicated

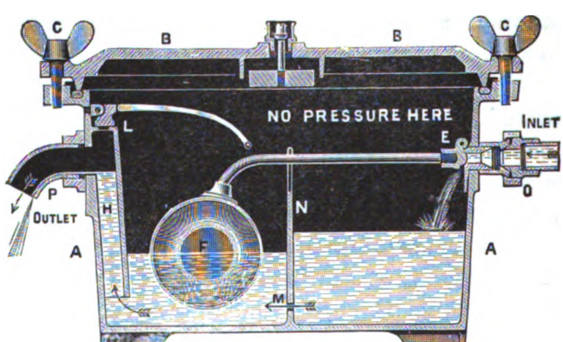

Fig. 153.—Royle's "Siphonia" Steam Trap.

by the arrows, through the siphon H, and into the outlet pipe P. When steam enters the trap, the water is driven out through the siphon by the pressure, which tends to accumulate; the ball F falls and closes valve E.

Fig. 154 shows the "Lancaster" steam trap, which consists of a cast-iron box fitted with a steamtight lid. The condense is led to a hollow arm, at one end of which a copper sphere is attached. The opposite end of the arm is connected to a brass union by a right-angled bend.

A quick-pitched thread in this connection causes a closing action when the arm is raised. As the condense passes into the copper sphere through a small aperture in the seating of the valve, the arm is depressed and the valve opens. The steam pressure forces the condense quickly into the trap and

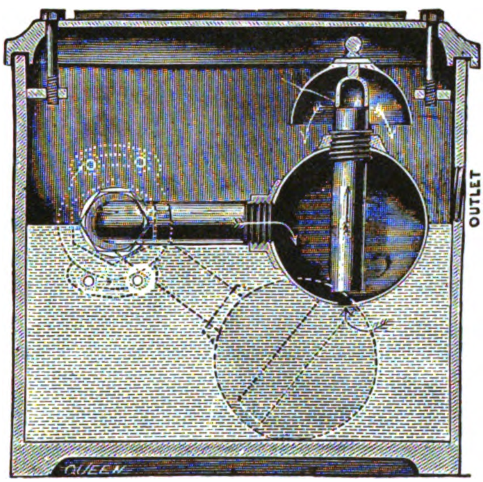

FIG. 154.—"Lancaster" Steam Trap.

fills the sphere with steam, driving out the water through the dip pipe. The steam is quickly condensed, water again enters the sphere, and the action is repeated.

The trap outlet may discharge into a drain, or the condense may be conveyed to a hot well for use in the boiler.

The transmission of heat through the walls of steam tubes used in heaters is influenced by the following factors:—

1*st.* The difference between the temperature of the steam on one side and the temperature of the water on the opposite side of the pipe wall.

2*nd.* The form of the tube, whether it be plain or possessing a broken or irregular surface.

3rd. The velocity of the steam, and also that of the water over the pipe surface or in the immediate vicinity of the pipe wall.

4th. Quick removal of condense and the exhaustion of all air from the tubes.

5th. The absence of deposits of lime or similar salts from the tube surfaces.

The first factor is of primary importance in the question of heat transmission as affecting calorifiers; although an increase in the rate of transmission takes place at higher steam temperatures other than the increase due to difference in the temperatures of the water and steam, it can be stated with a reasonable degree of accuracy that the average rate of *transmission of heat is equal to* 300 B.Th.U. *per square foot per hour* for each degree of difference in the temperatures of the water and the steam.

The second factor is also of importance. Generally, plain straight tubes transmit less heat per unit area than those that are bent or have their surfaces indented. This is due to the formation of vortices and eddies in a steam current passed through pipes showing broken surfaces which have the effect of dispersing or scouring the condense and cooled gases from the inner surface of the tube.

The third factor has a decided influence upon the rate of transmission under certain conditions. During condensation of the steam the condense tends to cling to the pipe wall, and to some extent acts as a non-conductor of heat, also on the opposite side of the pipe wall a film of warm water adheres. If the steam travels at a high velocity through the pipe, the eddies and vortices formed will scour the pipe walls, and the rate of transmission will be increased. Moreover, if means be taken to put the water in motion, so as to disperse the film mentioned, there will be a greater difference of temperatures maintained on the opposite sides of the pipe wall.

Factors four and five are also of importance. If the tubes be partly charged with air, the steam will mix with the air and thereby interfere with the process of rapid condensation; again, if the tubes be fixed horizontally without fall, or possess dips so that ponding of the condense occurs, their efficiency will be reduced.

In hard water districts, frequent cleansing of the tubes is essential for efficient working.

The steam tubes used in calorifiers vary in shape, according to the practice of the manufacturer.

Plain straight tubes are rarely used, but heaters having one or more **copper coils** are met with. The length of each coil should not exceed 120 times the internal diameter of the pipe, otherwise the lower part or extreme end of the pipe will have a very low efficiency.

Short lengths of pipes that are returned in parallel have a fairly high efficiency, owing to the breaking-up action that the bends have upon the current of steam.

The indented tube supplied in Royle's calorifiers has a heat transmission value per unit area which is nearly twice that of a straight tube tested under indentical conditions.

Fig. 155 shows a view and part section of the tube. The indentations have the effect of shortening the tube, thereby increasing the condensing surface per unit length compared with a circular tube of the same diameter; moreover, they accommodate the expansion and contraction due to temperature changes without straining the discs of the chambers to which they are attached.

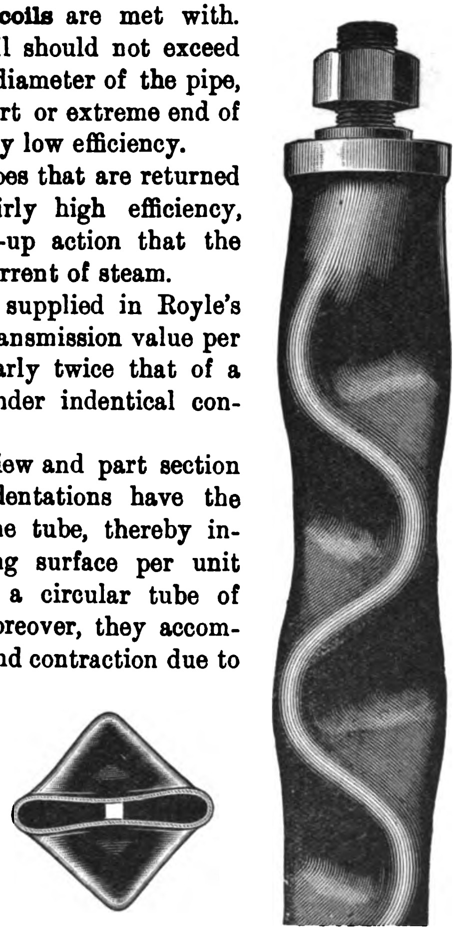

FIG. 155.—Row's Indented Tube.

The inner corrugated surfaces break up the current of steam, thereby increasing its scouring action and accelerating the rate of heat transmission through the pipe wall.

In calculations connected with the heating surface of steam coils, etc., it is necessary to assume mean temperatures for the water. From the previous explanation in reference to the rate of heat transmission, it will be observed that as the temperature

of the water increases, the rate of transmission will decrease; moreover, the average temperature of the fluid in contact with the steam surface of the tube will probably be less than its initial temperature.

The following table (pp. 217, 218) shows the temperature of steam at given pressures, also the latent heat. It will be noticed that the latter decreases with the increase of pressure under which the steam is generated. There is therefore no advantage in the use of high-pressure steam as regards the amount of B.Th.U. available on the condensation of a unit volume of steam. The only advantage is the increased rate of heat transmission, due to the greater difference in temperature of the steam and water.

It is generally accepted that a temperature of 180° F. is suitable for the circulating water in "low-pressure" heating installations; the same temperature is also recommended for the stored water in domestic hot-water services, although opinions differ on the latter point. The extremes advocated are 205° F. and 120° F.

It is contended that water at the former temperature is liable to injure the glaze on cast-iron baths; also, porcelain lavatory basins occasionally are fractured by discharges of very hot water. On the other hand, considerably less storage accommodation is required than that necessary for water at the lower temperature.

A temperature of 180° F. has, however, proved quite satisfactory as the result of many years of practice; moreover, there is little or no deposit of lime salts from hard water at this temperature.

The average temperature of the water in the street mains is generally taken as 50° F.

Assuming that the steam be used at atmospheric pressure, and that the water has to be stored at a temperature of 180° F., then the average rate of heat transmission per square foot of steam pipe = 300 B.Th.U. per degree difference between T_1 of steam and T_2 of water.

$$\text{Mean } T_2 \text{ of water} = \frac{180 - 50}{2} + 50 = 115$$

$$\begin{aligned} \therefore \quad \text{the average rate per hour} &= 300(212 - 115) \\ &= 29700 \text{ B.Th.U.} \end{aligned}$$

Table showing the Properties of Saturated Steam.

Absolute Pressure per square inch, measured from a Vacuum.	Temperature in Degrees Fahrenheit of Steam and of the Water from which it was evaporated.	Number of British Thermal Units contained in 1 lb., reckoned from Zero Fahrenheit.		Weight of 1 cub. ft. of Steam in Decimals of 1 lb.
		Number required for Evaporation, known as Latent Heat, or Heat of Vaporisation.	Total Number contained in the Steam.	
1	102·00	1042·96	1145·05	·0030
2	126·27	1026·01	1152·45	·0058
3	141·62	1015·25	1157·13	·0085
4	153·07	1007·23	1160·62	·0112
5	162·33	1000·73	1163·45	·0137
6	170·12	995·25	1165·83	·0163
7	176·91	990·47	1167·90	·0189
8	182·91	986·25	1169·73	·0214
9	188·32	982·43	1171·37	·0239
10	193·24	978·96	1172·88	·0264
12	201·96	972·80	1175·54	·0313
14	209·56	967·43	1177·85	·0361
*14·7	212·00	965·7	1178·60	·0380
16	216·30	962·66	1179·91	·0413
18	222·38	958·34	1181·76	·0462
20	227·92	954·41	1183·45	·0511
22	233·02	950·79	1185·01	·0561
24	237·75	947·42	1186·45	·0610
26	242·17	944·28	1187·80	·0658
28	246·33	941·32	1189·07	·0707
30	250·24	938·92	1190·26	·0755
32	253·95	935·88	1191·39	·0803
34	257·48	933·37	1192·47	·0851
36	260·83	930·97	1193·49	·0899
38	264·05	928·67	1194·47	·0946
40	267·12	926·47	1195·41	·0994
42	270·07	924·36	1196·31	·1041
44	272·91	922·32	1197·18	·1088
46	275·65	920·36	1198·01	·1134
48	278·30	918·47	1198·82	·1181
50	280·85	916·63	1199·60	·1227
52	283·33	914·86	1200·35	·1274
54	285·72	913·13	1201·09	·1320
56	288·05	911·46	1201·80	·1366
58	290·32	909·83	1202·49	·1411

* Normal atmospheric pressure.

Table showing the Properties of Saturated Steam—continued.

Absolute Pressure per square inch, measured from a Vacuum.	Temperature in Degrees Fahrenheit of Steam and of the Water from which it was evaporated.	Number of British Thermal Units contained in 1 lb., reckoned from Zero Fahrenheit.		Weight of 1 cub. ft. of Steam in Decimals of 1 lb.
		Number required for Evaporation, known as Latent Heat, or Heat of Vaporisation.	Total Number contained in the Steam.	
60	292·52	908·25	1203·16	·1457
62	294·66	906·70	1203·81	·1502
64	296·75	905·20	1204·45	·1547
66	298·79	903·73	1205·07	·1592
68	300·78	902·30	1205·68	·1637
70	302·72	900·90	1206·27	·1682
72	304·62	899·53	1206·85	·1726
74	306·47	898·19	1207·41	·1770
76	308·29	896·88	1207·97	·1814
78	310·07	895·59	1208·51	·1858
80	311·81	894·33	1209·04	·1901
82	313·52	893·09	1209·56	·1945
84	315·19	891·88	1210·07	·1989
86	316·84	890·69	1210·58	·2032
88	318·45	889·52	1211·07	·2075
90	320·04	888·38	1211·55	·2118
92	321·60	887·25	1212·03	·2161
94	323·13	886·14	1212·49	·2204
96	324·63	885·04	1212·95	·2245
98	326·11	883·97	1213·40	·2288
100	327·57	882·91	1213·85	·2330
105	331·11	880·34	1214·93	·2434
110	334·52	877·86	1215·97	·2538
115	337·81	875·47	1216·97	·2640
120	340·99	873·15	1217·94	·2743
125	344·07	870·90	1218·88	·2843
130	347·06	868·73	1219·79	·2942
135	349·95	866·62	1220·68	·3040
140	352·77	864·57	1221·53	·3139
145	355·50	862·57	1222·37	·3239
150	358·16	860·62	1223·18	·3340
160	363·28	856·87	1224·74	·3521
170	368·16	853·29	1226·23	·3709
180	372·82	849·87	1227·65	·3889
190	377·29	846·58	1229·01	·4072
200	381·57	843·43	1230 32	·4250
250	401·07	831·22	1235·73	·5464

One B.Th.U. will raise the temperature of 1 lb. of water through 1° F.

$\therefore$ number of pounds of water increased in temperature from 50° F. to 180° F. in one hour

$$= \frac{29700}{180 - 50}$$

and the number of gallons of water increased in temperature from 50° F. to 180° F. in one hour

$$= \frac{29700}{10 \times (180 - 50)}$$
$$= 23 \text{ galls. (approx.)}$$

Example.—Find the total length of 1 in. diameter steam tube that is necessary in a calorifier from which 200 galls. of water at 180° F. are required per hour. Temperature of incoming water, 50° F. Steam pressure = 50 lbs. per square inch.

Assuming that the mean T_2 of the water

$$= 50° + \frac{180° - 50°}{2} = 115° \text{ F.}$$

and the mean T_1 of the steam $= 297° - 20° = 277°$ F.

The total B.Th.U. required per hour $= 200 \times 10 \times (180 - 50)$
$= 260000$

1 sq. ft. of surface will transmit 300(277 − 115) B.Th.U. per hour.

$$\therefore \quad \text{total heating surface} = \frac{260000}{300(277 - 115)}$$
$$= 5{\cdot}3 \text{ sq. ft.}$$

$$\text{and length of 1-in. pipe} = \frac{5{\cdot}3}{\pi D} = \frac{5{\cdot}3}{\frac{22}{7} \times \frac{1}{12}}$$
$$= 5{\cdot}3 \times 12 \times 3{\cdot}142$$
$$= 20{\cdot}2 \text{ ft.}$$

In practice an addition of from 10 per cent. to 25 per cent. would be made to this quantity according to local requirements.

Generally, it is much better for the duty value of the appliance to be at least 25 per cent. above normal requirements.

CHAPTER X

BOILERS OF VARIOUS TYPES—HEATING SURFACES—EFFICIENCY OF HEATING SURFACES—BOILER EXPLOSIONS: CAUSES AND METHODS OF PREVENTING SAME

BOILERS that are used in connection with domestic hot-water services are of two kinds.

1. Those that are fixed in the kitchen grate or range.

2. Boilers that are self-contained and have separate fire-boxes. These are known as "independent boilers."

The success of a scheme of domestic hot-water services depends to a great extent upon the type of boiler that is used, and the manner in which it is fixed. Many otherwise good schemes fail or are unsatisfactory on account of the insufficiency of the heating surface of the boiler.

Where copper boilers are used, cost is sometimes responsible for a curtailment of their sizes. Such practice is certainly not economical, especially in the case of independent boilers. In systems that are equipped on this principle the boilers have to be fired under a continual maximum draught to enable them to cope with the normal demands. In consequence the fuel bill is out of all proportions to the reasonable requirements of the system.

Again, in houses where large quantities of hot water are required daily, the kitchen boiler will prove inadequate for the work. It should be remembered that the primary duty of the kitchen fire is that of cooking, and that the warming of water is a secondary matter. When the two operations coincide as regards their requirements, the latter has to give place to the former.

Cylinder and tank combined systems should in all cases be provided with independent boilers. Attempts are often made

to place the duty on the kitchen fire, various forms of boilers being adopted for the purpose of increasing the heating surface and absorbing a maximum amount of heat from the waste gases as they pass up the flues. Such a course is rarely satisfactory, and generally ends in the failure of the system, and, incidentally, the reputation of the designer suffers.

For a cylinder system, the maximum demands upon which will not exceed from 15 to 20 galls. of water at 180° F. per hour, a kitchen boiler may be used, but care must be exercised in the choice of the boiler, and the manner of fixing the same to ensure a reasonable degree of success.

The Materials used in the Manufacture of Boilers are copper, cast-iron, and wrought-iron.

Copper is the most suitable for use in districts supplied with soft water or water well aerated and containing acid; also, where rain-water from the roofs of the buildings is stored and supplied for domestic use. Copper is not acted upon by such water; moreover, owing to its fibrous character, it is not readily fractured by heavy or sudden blows.

Cast-iron is largely used for the manufacture of boilers of the smaller sizes. Although such boilers are often fixed in connection with soft or acid water supplies, they are not satisfactory on account of the rapid oxidation of their interior surfaces and the consequent discoloration of the water.

Attempts have been made to protect the iron by coating it with various substances, but without permanently successful results. "Bower Barffing" has been tried repeatedly, but the difficulties that are opposed to the process of coating the interior surface of a closed vessel have not been satisfactorily overcome.

For "hard-water" districts cast-iron boilers may be used, as the deposit of scale prevents the formation of rust.

Wrought-iron is, like cast-iron, unsuitable for use with "soft water," but can be adopted with advantage in "hard-water" districts. Owing to its fibrous nature, it will withstand shocks and strains without suffering apparent injury.

The hammering necessary to remove scale deposits is not liable to crack or fracture the boiler plates as in the case of cast-iron; moreover, thick deposits of scale are frequently found on the plates that receive the greatest amount of heat,

and in consequence they become red hot owing to the comparatively low rate of conductivity of the deposit. The scale becomes detached by the expansion of the iron assisted to some extent by the formation of steam between the two substances, and the water comes in contact with the red-hot iron. If it be cast-iron a fracture may occur, but if it be wrought-iron it will remain intact.

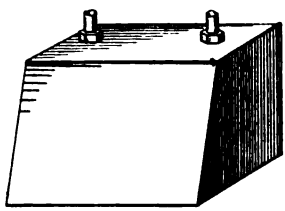

Fig. 156.—Box Type of Kitchen Boiler.

For kitchen fire grate purposes wrought-iron boilers are usually welded into shape. In many instances excellent seamless boilers of the "independent" type are made in the same way. The larger sizes of independent boilers have riveted joints.

Kitchen boilers are constructed in various shapes. Fig. 156 shows a common type of boiler suitable for fixing in an open grate or range. The front is usually sloped backwards from bottom to top. Greater efficiency would accrue if the slope were made in the opposite direction, more heat rays would be intercepted, and the heated gases would have a better scouring effect, thereby dispersing the cooled film in contact with the boiler plate.

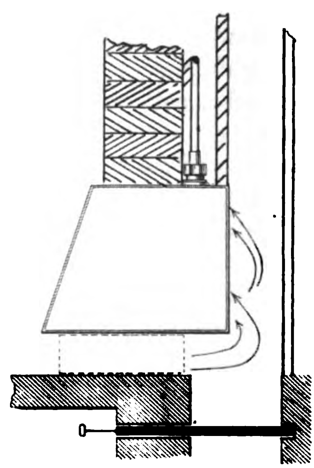

Fig. 157.—Boiler *in situ*, showing Ash Slide and Flue.

Fig. 157 shows the boiler *in situ*. Fire-brick supports of not greater width than 2 ins. are provided, which project the boiler 3 ins. above the bottom fire bars. The whole of the back of the boiler is exposed to the heated gases, and in addition a maximum amount of surface is available in front and at the bottom of the boiler.

To facilitate the cleansing of the flue, an ash slide is provided, which also allows of easy access to the flue.

The heat-absorbing surface of this type of boiler may be

increased by having an arched flue formed in the bottom plate, as shown in Fig. 158. It is necessary to raise the boiler at least 1½ ins. above the bottom fire bars by means of fire bricks, to provide sufficient flue space.

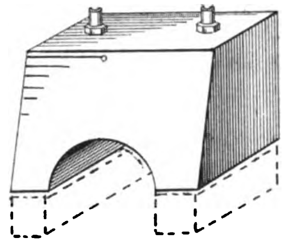

Fig. 158.—Boiler with Arched Flue.

The most effective portion of the heating surface is that which is in direct contact with the fire.

Fig. 159 shows a view of a boot boiler suitable for fixing in certain types of enclosed kitchen ranges. The toe A projects into the heart of the fire; also, practically the whole of the base and the top of the toe is in direct contact with the fire. Vertical flues are arranged at the back and front of the boiler, so that there is very little of the surface which is not exposed to the fire or to the effect of currents of heated gases.

It is usual in this boiler to connect the flow and return pipes to the top of the "leg" of the boiler. In the example given, the return pipe joins one side of the toe, thereby directing

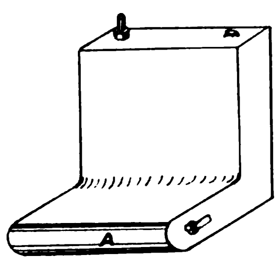

Fig. 159.—Boot Boiler.

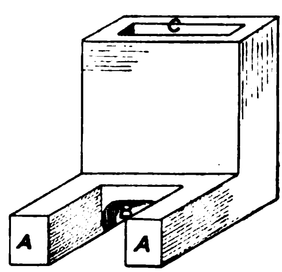

Fig. 160.—Boot Boiler (modified form).

a stream of water into the hottest part of the boiler and greatly facilitating the circulation.

Owing to the comparatively small water space and the large heating surface of this type of boiler, the water in the horizontal part is often boiling, and steam is generated owing to sluggish circulation in that part. The arrangement of the connection as shown will overcome this defect.

Fig. 160 shows a greatly modified form of boot boiler. The cheeks AA are practically in the heart of the fire; also, the

arched bottom flue B and the central flue C greatly increase the heating surface.

A double vertical flue can be arranged where space will permit, by constructing a brick shaft against the back-plate of the boiler, but little additional advantage is gained thereby.

It should be borne in mind that the efficiency of this boiler is largely dependent upon the amount of fire in the kitchen grate, also that the fire is required for other purposes, therefore the available quantity of heat is variable and limited.

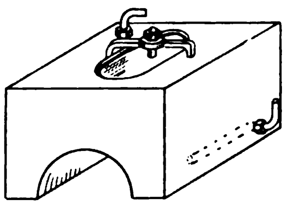

FIG. 161.—Closed Range Boiler.

Fig. 161 shows a view of a small but effective boiler for use in the closed type of kitchen range. Provision should be made for the fire and the heated gases to have full access to all parts of the boiler excepting the portions in contact with the brick supports; also, the back should be slightly higher than the front, to allow air which may be disengaged from the water to escape through the flow pipe.

For hard-water districts this form of boiler is well suited. The scale can be removed whilst the boiler is in position, if the manlid is made sufficiently large.

The flow pipe must be connected to the top and the return pipe to the bottom of one side of the boiler. From the return pipe a horizontal pipe should be used inside the boiler to convey the water towards the front plate where the maximum heating effect is experienced.

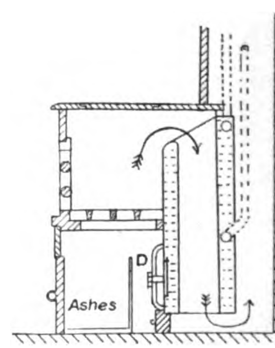

FIG. 162.—"Mermaid" Boiler.

For use with temporary hard water the boiler shown in Fig. 162 will give satisfaction. The lime salts accumulate principally in the lower part of the boiler, from which they are removed through the access door D. Little, if any, scale will be found on the inclined surface in contact with the fire.

Periodic scaling operations are essential to the successful use of this boiler. Its advantage is due chiefly to its shape,

which causes the deposit to be arrested below the effective fire-line; therefore its efficiency is not materially impaired by reasonable usage.

Care should be taken, when arranging or fixing the pipe connections to the boiler, to avoid the formation of air-pockets. The flow pipe should, where possible, be taken directly from the top plate; also, the boiler must be fixed either perfectly level or be tilted slightly so that air can readily pass into the flow pipe.

Draw-off or Emptying Pipes are an advantage when repairs are necessary; also, for the removal of sludge from the boilers. They should be fixed directly to the boiler in each case, and provided with cocks having detachable keys.

Independent Boilers may be of wrought-iron, cast-iron, or copper. The latter is to be used where the service water will have direct contact with the boiler — *i.e.* in the direct system — if the water be soft, slightly acid, or pure and well aerated. For hard water either cast or wrought iron can be used.

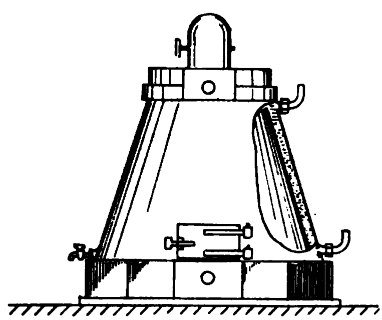

FIG. 163.—Independent Copper Boiler.

Copper boilers are very expensive, and if great care is not exercised in their use and management they soon require replacing.

Coke must not be used as a fuel in connection with copper boilers. It has a distinct action upon the metal during combustion, and thereby tends to materially increase the wear and tear.

Incautious use of the poker or slicing bar during firing is often responsible for fractured boilers. Attendants should be warned on this point, and occasional inspection of the boilers by responsible persons should be made to ascertain whether instructions are being complied with.

Fig. 163 shows a common form of independent boiler constructed of copper. The base and crown are of cast-iron and are detachable. The water space between the jackets varies with the diameter of the boiler from 2 ins. to 3 ins. It is

open at the top, where the smoke is led into the flue by the cast-iron crown, in which a damper is provided for regulating the rate of combustion. Boilers having vertical walls are not so efficient as those whose shape resembles a frustum of a cone, as illustrated by Fig. 163. The inclined surface receives a greater amount of radiant heat per unit area than a vertical surface would receive if fixed under similar conditions; moreover, the heated gases and flames from the fuel impinge with greater effect upon an inclined or horizontal surface, thereby scouring or dispersing the film of cooled gas in contact with the plate and increasing the rate of heat transmission.

If an abnormally large amount of heating surface be required, one or more horizontal water tubes can be arranged above the furnace, but the initial cost is greatly increased by this procedure.

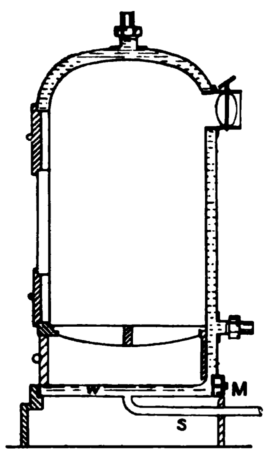

Fig. 164.—Dome-top Boiler.

Dome-top Boilers have a higher rate of efficiency per unit area than those possessing open tops, the reason being given in the previous paragraph anent inclined or horizontal surfaces.

For water which does not corrode iron this type of boiler in wrought or cast iron can be used with advantage. Fig. 164 shows a part section of a dome-top boiler. The water space W receives deposits of solids, which can be removed through the sludge pipe S. The shell is of wrought-iron and the base of cast-iron. A manlid, M, is also provided to facilitate the removal of scale or sludge.

The Duty of a Boiler is the amount of heat which it will transmit from the fire to the water in a given time.

The efficiency of a boiler depends upon several conditions:—

1st. The quantity of soot or scale on its surfaces.

2nd. The relative temperatures of the water and the fire.

3rd. Ratio of the area of the heating surface to the area of the fire bars (this applies to independent boilers).

4th. The relative quantities of "direct and indirect" heating surfaces.

5th. The kind of fuel used, also the height and cross-sectional area of the flue.

6th. The position of the direct surface in relation to the fire.

From the above it will be readily understood that it is not possible to devise a formula which will give accurate results for the many and varied conditions obtaining in the construction and fixing of boilers.

Surfaces that are in actual contact with the fire will receive and transmit from 20,000 to 40,000 B.Th.U. per square foot per hour, whereas the flue surfaces exposed to the heated gases, will not absorb more than one-twentieth of that amount. The deposit of soot on these surfaces is responsible for a considerable loss of efficiency, but it should be remembered that the temperature of the fire is much greater than that of the heated gases; moreover, the surfaces in direct contact have the additional advantage of radiant heat from the fire. Again, the efficiency of the different portions of the "direct" heating surface varies with their positions. Thus the parts in close proximity to the fire invariably receive the greater quantity of heat, and their surfaces are freer from soot and similar deposit than those situated above the fire.

To determine the effective heating value of kitchen range boilers, only the "direct" surface should be considered.

The "direct" surface is that which receives radiant heat from the fire, and the "indirect" is that which receives heat only from the evolved gases.

The direct heating surface of a kitchen range boiler is that offered by the front plate and the exposed portion of the bottom plate.

A moderate estimate will give the average heat transmission of 1 sq. ft. of kitchen boiler direct surface as 10,000 B.Th.U. per hour. In these calculations it will be assumed that 1 B.Th.U. will raise the temperature of 1 lb. of water through 1° F., irrespective of the initial temperature of the water.

Example.—A kitchen range boiler has a "direct" heating surface of $1\frac{5}{8}$ sq. ft.; find the time required to raise 30 galls. of water from 45° F. to 175° F. (1 gall. = 10 lbs.):—

$$1 \text{ gall. raised from } 45 \text{ to } 175 = 10(175 - 45) = 1300 \text{ B.Th.U.}$$

$$\therefore\ 30 \text{ galls. } \quad ,, \quad 45 \text{ to } 175 = 1300 \times 30 = 39000 \text{ B.Th.U.}$$

$$1 \text{ sq. ft. transmits } 10000 \text{ B.Th.U. per hour}$$

$$\therefore\ 1\tfrac{5}{8} \quad ,, \quad ,, \quad 10000 \times 1\tfrac{5}{8} \text{ B.Th.U. per hour.}$$

$$\text{Time required} = \frac{39000}{10000 \times 1\frac{5}{8}}$$

$$= 2 \text{ hours (approx.).}$$

Example.—How many gallons of water may be increased in temperature from 45° F. to 185° F. per hour, by using a kitchen boiler having direct heating surfaces as follows?—bottom 8 ins. × 14 ins., front 12 ins. × 10 ins.:—

$$\text{Total surface in square feet} = \frac{(8 \times 14) + (12 \times 10)}{144} = 1\tfrac{11}{18}$$

$$,, \quad \text{B.Th.U. per hour} = 1\tfrac{11}{18} \times 10000$$

$$,, \quad \text{gallons heated from } 45^\circ \text{ F. to } 185^\circ \text{ F.} = \frac{1\frac{11}{18} \times 10000}{10(185 - 45)}$$

$$= \frac{29 \times 10000}{18 \times 10 \times 140}$$

$$= 11\tfrac{1}{2} \text{ galls. (approx.).}$$

In the case of independent boilers a lower value is generally taken, for the following reasons:—

1st. The surface in "actual" contact with the fire is not so great comparatively as in kitchen range boilers.

2nd. The firing is not so evenly or carefully performed as in the latter case.

Generally, the heating surface of an independent boiler should be 25 per cent. greater than normal requirements. It is not economical to use boilers that are too small for the work. They have to be fired at the maximum draught, which entails an undue consumption of fuel, whereas by using a larger boiler, fuel combustion can go on more slowly.

Authorities differ as to the heating value per unit area of independent boilers for domestic hot-water supplies. Two thousand to 12,000 B.Th.U. per square foot per hour is the range of the estimates. Whilst the latter figure may be discounted as being too high, the former is undoubtedly too low. Taking into consideration the fact that the form as well as the size of a boiler will influence its heating efficiency, a figure is adopted which will meet the requirements of most cases.

In the following calculations it is assumed that one square foot of average boiler surface will transmit 6000 B.Th.U. per hour.

It should be distinctly understood that this figure refers to the conical-shaped boiler, in which the whole of the heating surface is in radiant contact with the fire.

Example.—It is required to determine the size of an independent boiler that will raise the temperature of 200 galls. of water from 45° F. to 185° F. in one hour.

Total B.Th.U. required per hour $= 200 \times 10(185 - 45)$.

1 sq. ft. of boiler surface transmits 6000 B.Th.U. per hour.

$$\therefore \quad \text{Boiler-heating surface required} = \frac{200 \times 10(185 - 45)}{6000}$$

$$= \frac{140}{3}$$

$$= 46\tfrac{2}{3} \text{ sq. ft.}$$

Independent boilers can be economically used in conjunction with unsatisfactory existing installations which are dependent upon kitchen boilers.

Generally, it is only necessary to maintain the fire in the independent boiler during the portion of each day when the demand is greatest.

Proper adjustment of dampers is essential to perfect combustion, otherwise CO (carbon monoxide) will pass away up the flues. This means that a considerable amount of fuel is going to waste. If a sufficient supply of air were available, the CO would be oxidised into CO_2, evolving a further quantity of heat during the process of combustion.

The calorific value of coal varies considerably. Under the best conditions, not more than 75 per cent. of the heat is obtained from the fuel used, and generally not more than 50 per cent. is converted into effective or useful work in domestic hot-water supply systems.

Calorific Values of Fuels.

1 lb.	anthracite coal	14,000 B.Th.U.
,,	cannel coal	13,000 ,,
,,	bituminous coal	12,000 ,,
,,	petroleum oil	20,000 ,,
,,	coke	10,000 ,,

Access to kitchen boilers for the purpose of removing the scale must be provided in hard-water districts.

The simplest arrangement consists of a large oval-shaped manlid fitting inside the boiler with a bridle outside, to which it is secured by means of a nut and bolt, as shown in Fig. 165.

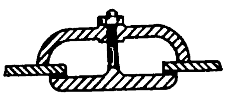

FIG. 165.—Manlid for Boiler.

The lids must be large enough to allow freedom for working with a chisel inside the boiler; also, they must be placed in such positions as will facilitate the cleaning operations.

Screwed plugs of large diameter are useless for the purpose. They are difficult to make watertight, and often become so firmly fixed as to defy all efforts to remove them.

Boiler explosions in connection with domestic services occur with monotonous regularity each year. In some instances they are responsible for loss of life, whilst they invariably occasion injury to some of the people who are near the boilers when they explode.

It is stated that kitchen boiler explosions are due to the following causes:—

1st. Stoppage of the circulation pipes by ice.

2nd. Stopcocks fixed on the circulation pipes being closed.

3rd. Incrustation, which eventually blocks both of the circulation pipes.

4th. The sudden discharge of water into an empty boiler, the plates of which are heated to redness.

Nos. 1 and 2 are responsible for explosions, but 3 and 4 are not.

Incrustation occurs principally in the flow pipe, the return pipe is generally found to be comparatively free from deposit.

To cause an explosion both pipes must be blocked and the boiler hermetically sealed. The noises that would be occasioned in the boiler by the contraction or total blockage of the flow pipe would compel the householder to have the matter attended to, long before the return pipe could become choked with deposit.

With regard to No. 4, no case is on record of a boiler having exploded by this means. Even assuming that one of the circulation pipes is blocked, the excess of pressure would

force the water back into the cylinder through the open pipe.

Experiments have been undertaken to prove or disprove this theory, and in each case the pressure generated immediately on the entry of the water did not exceed 45 lbs. per square inch; moreover, the boiler, which was of wrought-iron, remained intact.

If the boiler be of cast-iron, it is very probable that it would be fractured; but a fractured boiler is not necessarily an exploded boiler.

The householder has no means of determining whether the boiler and circulation pipes are free from ice before lighting the kitchen fire, and as explosions caused by frost are liable to occur in most domestic hot-water systems, an automatic appliance should be provided on all boilers, which will release an excess of pressure in the event of the circulation pipes being blocked by ice.

The term **safety valve** is applied to any one of the various devices that are attached to boilers to relieve the pressure.

There are four principal types of safety valves:—

1*st*. Dead-weight type.
2*nd*. Spring type.
3*rd*. Disc type.
4*th*. Lever type.

In addition, there are the "mercury column," which is rarely used, and the "fusible plug." The latter is quite unreliable, and should not be used.

Fig. 166 shows a section through one of the "dead-weight" type of safety valves. The valve has a fibre washer, A, and the weights consist of discs of cast-iron. The number required can be varied to suit requirements.

The advantage of this valve is its certainty of action; also, it automatically releases the pressure and then reseats itself.

Fig. 167 shows the "spring type," in which the valve is held in position by an enclosed spring of brass. The necessary tension is obtained by regulating the screwed cap N, which is eventually locked by means of the back nut C.

Like the dead-weight valve, this also is automatic in opening

and closing; but the spring is liable to decay, and loss of torsional strength which may result in leakage past the valve;

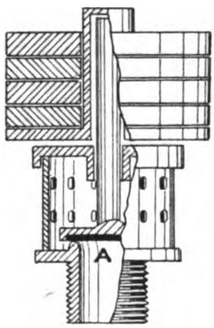

Fig. 166.—Dead-weight Safety Valve.

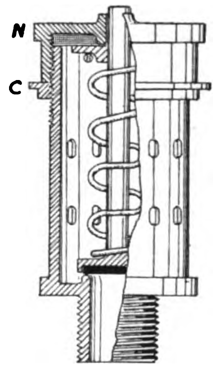

Fig. 167.—Spring Safety Valve.

moreover, it is difficult to accurately adjust the spring to obtain the requisite pressure.

The "disc" valve is shown in Fig. 168. It consists of a brass bush in which a thin disc of mica, sheet-copper, zinc, or lead is secured at A. The valve is screwed into the top of the boiler. The projection B prevents the water from coming in contact with the disc A, owing to the accumulation of air therein. Thus the risk of the deposit of lime salts on the under side of the disc is minimised.

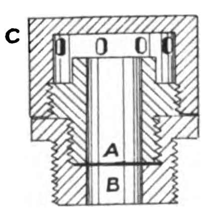

Fig. 168.—Disc Valve.

When an abnormal pressure accumulates, the disc is displaced and the excess released.

The cap C prevents dust or soot accumulating on the top of the disc.

This valve is cheap and reliable, and does not occupy much space.

The "lever" type of safety valve is rarely used on kitchen range boilers, owing to the large space which it occupies and the ease with which it is disturbed.

The position which a safety valve is to occupy should receive attention. In all cases valves must be fixed directly on

the boilers and not on the circulation pipes, or on special pipes connected with the boiler.

Where this precaution is neglected, the circulation pipes between the boiler and the valve may be ice-bound when the kitchen fire is lighted. Ice is a poor conductor of heat, and in consequence melts but slowly, especially in pipes which pass through walls; therefore the boiler may explode before the pipe between it and the safety valve is freed from ice.

Covers of cast-iron placed over the valves should be used to prevent soot and dirt from accumulating around the valves and hindering their freedom of action.

CHAPTER XI

CYLINDERS, TANKS, PIPES, AND FITTINGS — CALCULATIONS OF CAPACITIES — CAPACITY REQUIREMENTS OF SYSTEMS — GEYSERS

Cylinders are made of copper or wrought-iron. The latter, which is invariably galvanised, is suitable for use in hard-water districts, but where soft water is supplied copper cylinders must be used.

The thickness of the copper used for the manufacture of cylinders is rarely greater than 16 B.W.G., and is oftener 18 or 20 B.W.G.

Wrought-iron cylinders are made of plates which vary from $\frac{3}{32}$ in. to $\frac{5}{16}$ in. in thickness. Good results are obtained by the use of $\frac{5}{16}$ in. plates. The joints are riveted, and the cylinder is galvanised previous to completion.

Hand-holes or manlids are generally provided in wrought-iron cylinders to allow of access for the removal of sludge or scale. They should be sufficiently large to permit of easy access to all parts of the interiors of the cylinders.

Galvanised wrought-iron pipes are invariably used in connection with cylinders made of the same metal. The arrangement generally provided for connecting the pipes to the cylinder consists of a screwed flange riveted to the cylinder. It is common practice to screw the pipes directly into the flanges; but a better method is to insert ground unions between the cylinder and the pipes. By this means, the cylinder or the individual pipes can be disconnected without necessitating cutting the latter.

The positions of the cylinder connections should receive some consideration. It is the usual practice to connect the flow and return pipes at points within 9 ins. of the

bottom of the cylinder, a space of 4 to 5 ins. being allowed between the two pipes, as shown in Fig. 169, A B. To obtain hot water, practically the whole of the cylinder-content above A has to be raised to a uniform temperature. If the water in the cylinder is cold when the fire is lighted, it will not have attained the desired temperature before the expiration of from one to two hours.

If the flow pipe be connected as shown at C, hot water will accumulate in the portion C D within half an hour after lighting the fire. Moreover, the extra length between A and C increases the circulating head and consequently the velocity of the flow between the boiler and cylinder.

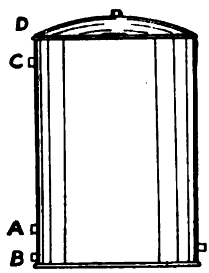

Fig. 169.—Cylinder Connections.

All Secondary Returns should enter the cylinder at points that are not less than 1 ft. below the top. The practice of connecting these pipes near to the bottom of the cylinder is often responsible for a partial failure of a system during a period of heavy demand. If the water in the lower portion of the cylinder is cold, then the fittings nearest the cylinder, which are supplied through the secondary returns, will draw either cold or lukewarm water; whereas, if the pipes be connected as suggested, the whole of the hot water below the connections of the cylinder is available for supply purposes.

Where feasible, the secondary returns may with advantage enter the top of the cylinder.

The Cold Supply should be continued from the tank to the cylinder without any bends, if possible, and should be provided with a full-way stopcock or valve. The latter may be fixed in the side or bottom of the tank, or it may be inserted on the pipe line near to the cylinder. There is no advantage obtained by connecting this pipe directly to the boiler.

The Air Pipe, or expansion pipe, must be continued vertically from the cylinder through the roof, or to a point about 1 ft. 6 ins. above the maximum water-level in the cold supply tank. In the former position it is liable to become ice-bound during frosty weather, and in the latter position the escape of steam may cause some inconvenience.

The air which is released or disengaged from any ordinary drinking-water when the latter is heated, also steam which may be formed during a period of minimum demand when the boilers are fired at the maximum, escape through this pipe.

Collapse of Cylinders is usually due to the displacement of their water-content by steam. The sudden condensation of the latter when cold water enters the cylinder is responsible for the formation of a partial vacuum. The reduced pressure in the interior is not sufficient to support the sides against the greater pressure of the atmosphere on its exterior, and in consequence the cylinder walls are crushed or bent inwards.

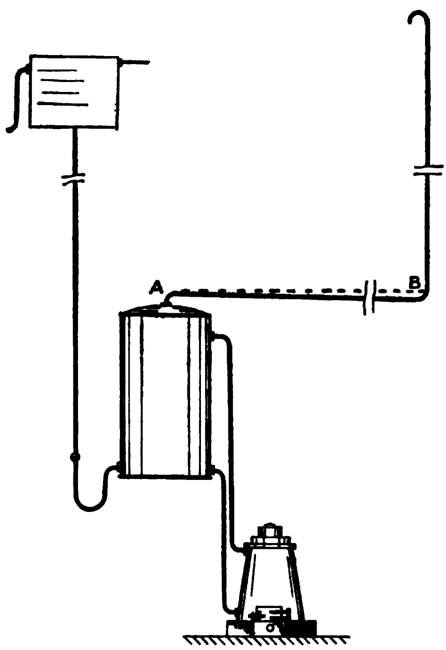

FIG. 170.—Cylinder Collapse.

It is popularly supposed that cylinders collapse only during frosty weather. Although this is generally the case, it is not exclusively so.

A case occurred recently during a hot day in summer. The pipes were arranged as shown in Fig. 170. The 2-in. diameter air pipe, which was 60 ft. long, had an inclination in the wrong direction in the portion A B. The upper end terminated on the roof some 6 or 7 ft. above the free surface of the water in the cold supply tank. The collapse was brought about in this wise. The independent boiler was filled with coal at mid-day, and the damper opened fully. The water in the cylinder quickly reached boiling-point, steam (which was generated in large quantities) accumulated in the top portion of the cylinder and gradually forced the water therefrom back again into the cold-water supply

tank. The inclined portion of the air pipe acted as a trap and prevented the escape of the steam; moreover, the greater vertical height of this pipe caused the water from the cylinder to force the lesser column to pass into the cold supply tank.

When the fire in the boiler commenced to wane, the steam pressure in the cylinder was lowered, and, water rushing in through the cold supply pipe, suddenly condensed the steam, and caused the formation of a partial vacuum. The water in the air pipe was exhausted into the cylinder, but a sufficient quantity of air could not pass into the cylinder quickly enough to prevent the sides being crushed in by the greater pressure of the air on the exterior surface.

The conditions obtaining during frosty weather that are generally responsible for the collapsing of cylinders are the stoppage of the air pipe by ice and the forcing of the water from the cylinder into the cold supply tank by steam. The subsequent condensation of the latter, as explained previously, causes the collapse.

Cylinders formed of wrought-iron, owing to their strength, are rarely collapsed.

To prevent Collapsing of Cylinders, vacuum valves should be fixed directly on the latter. Fig. 171 shows a part section through one of these. The pressure of the water in the system keeps the valve on its seat, but when the pressure of the atmosphere is greater than that tending to keep the valve closed, air is admitted to the cylinder and equilibrium is restored.

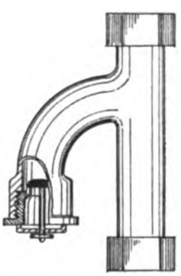

Fig. 171.—Vacuum Valve.

Copper cylinders are also corrugated to strengthen the walls to resist the external pressure, but it is questionable whether this method is efficacious.

To determine the Capacity of a Cylinder.—The area of the base in feet, multiplied by the vertical height in feet, will give the capacity in cubic feet. If it be required in gallons, multiply the product by $6\frac{1}{4}$ (*i.e.* $6\frac{1}{4}$ galls. equals 1 cub. ft.).

Example.—Find the capacity in gallons of a cylinder:

diameter equals 2 ft. 4 ins., vertical height equals 4 ft. 6 in.

$$\text{Capacity in gallons} = \text{area of base} \times \text{vertical height} \times 6\tfrac{1}{4}$$

$$= \frac{\pi \times D^2}{4} \times H \times 6\tfrac{1}{4}$$

$$= \frac{22}{7} \times \frac{1}{4} \times \frac{7}{3} \times \frac{7}{3} \times \frac{9}{2} \times \frac{25}{4}$$

$$= \frac{1925}{16}$$

$$= 120\tfrac{5}{16} \text{ galls. (approx.)}$$

If it be required to find the diameter of a cylinder of known height to hold a given number of gallons. The "gallons capacity," divided by $6\frac{1}{4}$ and by the height, equals the area of the base.

$$\text{Area of base} = \frac{\text{gallons}}{H \times 6\frac{1}{4}}$$

To find diameter from the area.

$$D = 2\sqrt{\frac{\text{area}}{\pi}}$$

Example.—Find the diameter of a cylinder to hold 80 galls. if the height be 4 ft.

$$\text{Area of base} = \frac{\text{gallons}}{H \times 6\frac{1}{4}}$$

$$= \frac{80}{4 \times \frac{25}{4}}$$

$$= \frac{80}{1} \times \frac{1}{4} \times \frac{4}{25}$$

$$= 3{\cdot}2$$

$$D = 2\sqrt{\frac{\text{area}}{\pi}}$$

$$= 2\sqrt{\frac{3{\cdot}2}{3{\cdot}14}}$$

$$= 2 \text{ ft. (approx.)}$$

If the diameter and capacity be given, to find the height,

divide the capacity in gallons by $6\frac{1}{4}$ and by the area of the base.

Example.—Find the height of a cylinder required to hold 75 galls. if the diameter be 1 ft. 9 ins.

$$
\begin{aligned}
H &= \frac{\text{capacity}}{6\frac{1}{4} \times \text{area of base}} \\
&= \frac{75}{\frac{25}{4} \times \frac{22 \times 21 \times 21}{7 \times 4 \times 12 \times 12}} \\
&= \frac{75}{1} \times \frac{4}{25} \times \frac{7}{22} \times \frac{4}{1} \times \frac{12}{21} \times \frac{12}{21} \\
&= 5 \text{ ft. (approx.)}
\end{aligned}
$$

The quantity of hot water to be stored should be governed by the number of the fittings which require supplies of hot water; also, any special features in connection with the use of the fittings should be taken into account.

The temperature at which it is desired to store the water will also have some influence on the quantity to be stored. It is usual to adopt a storage temperature of 180° F. If lower temperatures are desired, larger storage accommodation will be necessary.

In the case of large systems to be installed in houses and public institutions where continued usage of the fittings is probable during certain periods of each day, the duty value of the calorifier or the boiler must be sufficient to meet the heavy demand, or additional storage must be provided. The former will generally give the most satisfactory results.

When estimating the quantity to be stored, it should be remembered that the temperature of the water required for personal ablutions does not exceed 115° F., and is more often below rather than above this temperature. Assuming that the hot water be stored at 180° F. and the cold water is not more than 50° F., 1 lb. of hot water at 180° F. mixed with 1 lb. at 50° F. will produce a mixture having a temperature of 115° F.

1 lb. of water cooled from 180° F. to 115° F. gives out 65 B.Th.U.

1 lb. of water raised in temperature from 50° F. to 115° F. receives 65 B.Th.U.

The quantities to be stored for each of the various fittings are :—

Baths, 20 galls. (for normal usage).
Lavatories, 2 to 5 galls. (according to usage of fittings).
Wash-up sinks, 5 to 10 galls. (according to size of fittings).
Housemaids' or slop sinks, 8 to 15 galls. (according to usage of fittings).

These figures are for water stored at 180° F. (approx.).

Example.—Find the storage accommodation necessary for a cylinder and tank combined system in a mansion where there are 6 baths, 16 lavatories, 2 wash-up sinks, and 4 housemaids' sinks to be supplied with hot water at 180° F.

				Galls.
6 baths at 20 galls. . .	=	6×20	=	120
16 lavatories at 2 galls.. .	=	16×2	=	32
4 housemaids' sinks at 10 galls.	=	4×10	=	40
				192

In this example 200 galls. storage would therefore be sufficient.

The heating capacity of the boiler should be sufficient to raise the temperature of the water to the requisite degree within from two to two and a half hours.

In exceptional cases where the baths will probably be used several times within a period of one or two hours (a condition which invariably obtains in certain public institutions), additional heating surface will have to be provided.

In the foregoing example, assuming that the water is to be heated to the desired temperature in two hours, the boiler surface required

$$= 200 \text{ galls. raised from } 50^\circ \text{ F. to } 180^\circ \text{ F. absorb}$$

$$200 \times 10(180 - 50)$$

$$= 2000 \times 130$$

$$= 260000 \text{ B.Th.U. in 2 hrs.}$$

$$\text{in 1 hr.} = \frac{260000}{2}$$

$$\text{boiler surface} \doteq \frac{260000}{2 \times 6000} = 22 \text{ sq. ft. (approx.).}$$

Allowance must be made for loss of heat by radiation from the pipes, cylinders, and hot tanks. In connection with this

matter the necessity of covering these surfaces with a poor conductor of heat should receive attention. Even when the surfaces are covered, a limited quantity of heat is lost from them.

If radiators or hot towel-rails be used, their radiation requirements must be ascertained, and provided for in the boiler-heating surface.

Assuming that ten towel-rails are to be added to the previous example, each of which consists of 16 ft. of $1\frac{1}{2}$ in. copper or brass tube, the following calculation will give the additional boiler surface required:—One square foot of radiator pipe surface will evolve 1·8 B.Th.U. per hour per degree difference between the temperature of the water and the air.

Assuming the average temperature of the former to be 170° F., and the average temperature of the air to be 50° F., each square foot will emit

$$
\begin{aligned}
&1{\cdot}8(170-50) \\
&= 1{\cdot}8 \times 120 \\
&= 216 \text{ B.Th.U. per hour,}
\end{aligned}
$$

the total radiating surface of the ten towel-rails

$$= 10 \times 16 \times 2\pi R,$$

and the total B.Th.U. emitted per hour

$$
\begin{aligned}
&= 216 \times 10 \times 16 \times 2\pi R \\
&= \frac{216}{1} \times \frac{10}{1} \times \frac{16}{1} \times \frac{2}{1} \times \frac{22}{7} \times \frac{1}{16} \\
&= 13577
\end{aligned}
$$

$$
\begin{aligned}
\text{Additional boiler surface } &= \frac{13577}{6000} \\
&= 2\tfrac{1}{4} \text{ sq. ft. (approx.)}
\end{aligned}
$$

Pipes, Pipe Fitting and Jointing.—Lead pipes are not suitable for hot-water conveyance owing to the permanent enlargement which occurs under the varying temperatures experienced, also on account of the low tensile strength of the metal. Where long lengths are necessary, the pipes bulge, become distorted, and eventually fracture near to the joints and fixings.

The joints used on lead pipes must be of the plumbers' wiped type. Copper-bit joints, blown joints, or patent joints are not suitable, as they invariably fail after a short period of use.

In horizontal or inclined positions, the pipes must be supported on wooden fillets securely attached to the walls.

Lead pipes fixed vertically should be secured to 1-in. boards of sufficient width to accommodate the pipes and clips or lugs. The latter should be fixed at not greater distances apart than 2 ft. If clips be used, they should be of tinned steel or brass of a minimum width of 1½ ins.

Pipe hooks must not be used for this purpose.

During recent years light section copper pipe has been largely used on many of the better class of installations in soft-water districts.

Although more expensive than lead pipe, it possesses many advantages over the latter. It is neater in appearance, requires less support, and when properly fixed it is practically indestructible.

Pipes up to 2 ins. diameter and of 16 B.W.G. thickness will satisfy all requirements. They are improved in appearance by tinning their interior and exterior surfaces.

The bending of Copper Pipes of light section requires careful manipulation. It is essential that the pipe be loaded at the point where the bend is required with either molten lead, resin, or a mixture of bitumen and resin, to maintain an even cross-section.

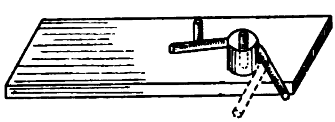

Fig. 172.—Device for bending Copper Pipes.

If a pipe-bending machine is available the work is greatly simplified. A temporary device, which is very serviceable and can be quickly rigged up, is shown in Fig. 172. It consists of a plank 3 ins. thickness in which two 1-in. diameter bolts are inserted about 6 or 8 ins. apart. Over one of these a short length of cast-iron pipe 4 ins. or more in diameter is placed. The other bolt acts as a fulcrum whilst the bend is being made.

The bends should be made to a radius of not less than five times the diameter of the pipe. The loading material must be carefully removed immediately each bend is formed. The absence of stoppages should be determined by blowing air through each length of pipe previous to fixing the same.

Joints on Copper Pipes have received special attention during recent years. The commonest form of joint consists of

a "shallow cut" thread, which is "tinned" before being screwed into the coupling, tee, or elbow. The threads in the fittings are also tinned, and the joint is screwed up whilst in a heated state.

The fluxes used in the tinning operations should consist of tallow and resin, or a mixture of stearin and vaseline.

Zinc chloride or similar fluxes must not be used.

It is an advantage if the sockets and tees are recessed, as shown at A in Fig. 173.* This will permit of the complete

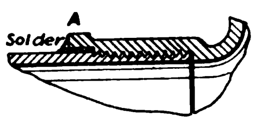

Fig. 173.—Screwed and Sweated Copper Joint.

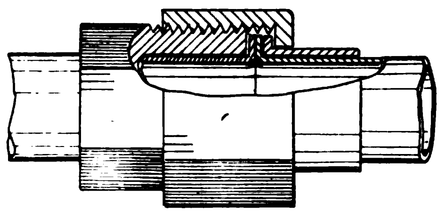

Fig. 174.—Royle's Compression Joint.

housing of the threads on the pipe, thereby obviating the liability of fracture.

Several patent joints are available for use in connection with copper pipe.

Fig. 174 shows a part section through one of these. The pipe ends have the two parts of the union placed over them, and are then flanged in a special machine. The screwing up

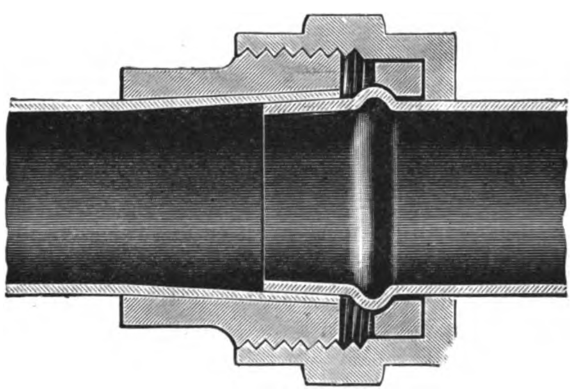

Fig. 175.—Leigh's Compression Joint.

of the union brings the two flanges together, and forms a water-tight joint without the aid of a packing material.

* By permission of the designer, L. Quirk, Esq.

Fig. 175 shows Leigh's "compression" joint, which may be adopted for the same purpose. The pipe ends are formed to the shapes indicated by means of special tools. During the screwing up of the union, one pipe end is gradually forced into the other until a watertight joint is formed between the two apposing surfaces of the copper pipes.

These joints are thoroughly reliable, and their use is especially recommended with light section copper pipes of less thickness than 14 B.W.G.

Expansion Joints or Loops are necessary on long lengths of either copper, wrought-iron, or cast-iron pipes used for hot-water purposes. This is especially so where branch pipes are connected to them; or, the opposite ends of the pipes are rigidly fixed.

If fractured or distorted pipes are to be prevented, provision must be made for accommodating the variation of the length of the pipes due to expansion and contraction.

In long vertical lengths of pipe an offset may be formed at the lower end to accommodate any variation of length.

Fig. 176 shows a part section of an expansion joint consisting of a packing gland in which a sleeve of gunmetal or brass is free to move.

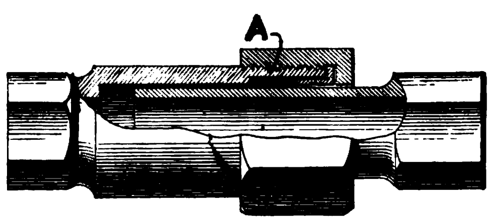

Fig. 176.—Expansion Joint.

For comparatively short lengths between rigidly fixed branches, this joint is satisfactory.

Asbestos is not a suitable material for use in the gland. Good quality hemp soaked in a mixture of stearin and graphite will give good results.

For comparatively long lengths the loop shown in Fig. 177 is more suitable than the expansion joint. Where a considerable range of movement is experienced, the latter is liable to leakage, and requires frequent attention. The "loop" should be fixed horizontally to prevent lodgment of air.

It is urged against the latter that its use greatly impedes the flow of water through the pipes. This is true to some extent, but if the bends be formed to a radius of twelve times the diameter of the pipe, the contention cannot be sustained.

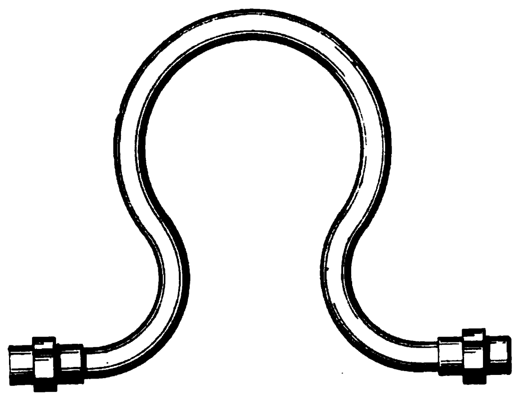

FIG. 177.—Expansion Loop.

The Fixing of Copper Pipes in vertical positions offers no special difficulties. Brass clips are suitable where the pipes are to be fixed on wooden grounds, but for plastered surfaces or tiled walls the use of stanchion supports is advisable.

Fig. 178 shows a horizontal section through a stanchion clip. The spike S is driven into the wall by striking the shoulder T; the part F is then screwed to it. The clip C is secured to F by means of brass bolts, and thus holds the pipe rigidly in position, whilst it is also easily detachable.

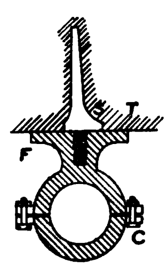

FIG. 178.—Stanchion Support for Copper Pipes.

Pipes fixed horizontally or at an inclination require careful treatment.

In the case of long lengths of pipes of large diameter, it may be advisable to provide antifriction rollers to allow freedom of movement when the pipes are expanding or contracting. For light section copper pipes the supports should be fixed at intervals not exceeding 3 ft., or wooden fillets may be fixed under the entire length of the pipes.

The minimum inclination for either primary or secondary circulating mains should, wherever possible, be not less than $\frac{1}{16}$th of an inch per foot-run.

The Screwed Joint is in common use on wrought-iron pipes. The lute or packing material with which the threads are coated varies with the practices obtaining in different districts. Mixtures of white and red lead in linseed oil are generally adopted. The threads are closely invested by strands of hempen fibre before the lead mixture in the form of paint is applied to them.

A stiff paste formed of graphite and linseed oil will give excellent results; moreover, pipes jointed with this substance are more easily detached than those jointed with a lead mixture.

Taps and Valves.—Stopcocks or valves used on hot-water services should be of the "full-way" type. Peet's valve, two forms of which are shown in Fig. 90, will give satisfactory results. They can be shut off drop-tight; also, they offer very little resistance to the flow of water when turned "full on."

The draw-off taps are best of the "screw-down valve" type. The Kelvin tap is useful for this purpose. Plug bibcocks are not suitable, owing to the frequent renewals or repairs that are necessary to maintain them in a satisfactory condition, and to the loss of water which they occasion by leakage.

Fibre washers should be used in the ordinary pattern screw-down valve tap; for hot-water purposes the leather washer is unsuitable.

The use of coal-gas for heating the water required in baths, lavatories, and sinks has made appreciable headway during recent years.

Geysers are appliances used for this purpose.

Many houses have not the usual domestic hot-water service installation. Any such system which is inserted at the expense of the tenant becomes a fixture, and consequently is the property of the landlord. But the tenant can have a gas-heater fixed or removed at will, provided no damage is caused thereby to the landlord's property.

Geysers are also suitable for use in clubs, golf-houses, bungalows, public lavatories, and buildings, the occupation of which is of a temporary or intermittent character.

They are easily fixed and controlled; moreover, the water

is rapidly heated, and a supply is available immediately after lighting the gas.

They can be obtained in sizes to suit all requirements.

Geysers are of two types—1*st*, "open"; 2*nd*, "sealed."

The former consists of an arrangement of open conduits or passages grouped inside a cylindrical casing of sheet copper. The water in its passage through the geyser travels through

Fig. 179.—Ewart's "Champion" Geyser.

these conduits, and is brought into contact with the products of combustion from the gas jets in the base of the heater. It is therefore contaminated and rendered unfit for cooking or drinking purposes.

The whole of the interior parts should be made of heavily tinned copper.

Fig. 179 shows a simple form of the "open" type. The

burner is hinged so that it may swing clear of the cylinder to prevent an explosion occurring when lighting it.

The water is admitted to the funnel-shaped intake, and passes from the spout into the bath, lavatory, or other fitting.

It is usually fixed at a convenient level above the fittings to be supplied.

The burners used in geysers are of two kinds—the "Bunsen" and the "white flame." The latter is the one most commonly

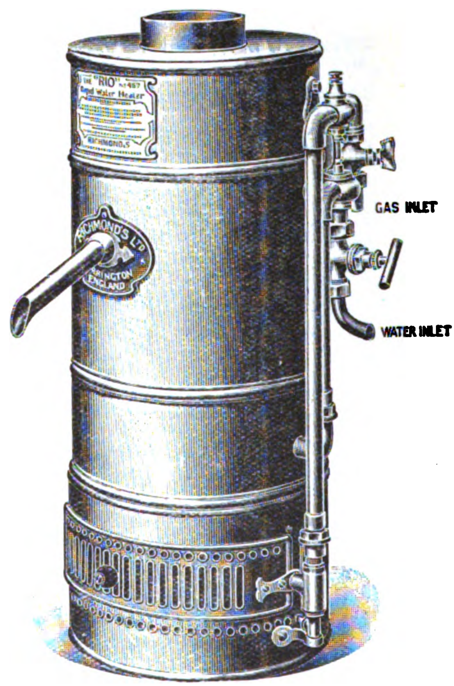

FIG. 180.—Richmond Geyser.

used, as the products of combustion are not so injurious as those produced in the Bunsen burner.

The efficiency of the Bunsen burner per unit volume of gas consumed is much higher than that of the white flame pattern, but the CO which is given off when the flames come in contact with cold surfaces are especially deleterious to health.

All geysers should be provided with an arrangement by which the water is turned on automatically when the gas-

supply cock is opened, otherwise there is a risk of the inner chambers or conduits being overheated and damaged; also, a sudden rush of steam from the outlet may occur when the water is turned on, thereby rendering the operator liable to scalding.

The "sealed" pattern of geyser is of two kinds:—

1. That in which the water flows through an open spout at the same speed at which it enters the internal chambers. The water conduits are not under pressure, excepting that due to the difference in level of the inlet and outlet where the latter is higher than the former.

2. The "under-pressure" type, which is made sufficiently strong to withstand a pressure of 100 lbs. per square inch. This apparatus is used principally as the sole means of supply of hot water to the fittings in various parts of a building.

In the "sealed" type the inner water conduits, which are entirely enclosed, usually consist of coils or batteries of copper tubes.

Fig. 180 shows a "sealed" geyser of the non-pressure type, the water inlet of which is below the outlet. The gas and water cocks are connected together by means of a rod, which operates them simultaneously. The burner is of the fixed kind, and is lighted by a "pilot" light when the gas is turned on.

A Pilot Light consists of a very small gas flame fixed over the burner. The gas supply to it is maintained through a by-pass arrangement. The "pilot" is usually kept lighted during the day, but is turned off at night.

This arrangement obviates any risk of explosion, as immediately the gas is turned on it becomes ignited.

The water supply to a geyser requires special consideration. In the "open" type no difficulty is offered, as the water supply is entirely disconnected from the geyser, but the "closed" type requires to be connected to the water pipe. If the latter be in direct communication with the street main, the connection will probably be objected to by the local waterworks authority, owing to the risk of pollution of the water in the main. A supply from a cistern or tank is essential to comply with the regulations of most waterworks authorities.

In hard-water districts the "open" type of geyser is generally used, as the temperature of the water in the heater is

rarely raised above 170° F. At this temperature there is little risk of precipitation of lime salts occurring.

If the "sealed" type is to be used in conjunction with temporarily hard water, a thermostatic valve should be provided to regulate the gas supply so that the water temperature will not exceed 170° F. The valve can be adjusted for temperatures between 120° F. and 170° F., and can generally be relied upon to work satisfactorily within a range of from 35° to 50° F.

A pilot light is generally provided in conjunction with this valve, so that the gas in the burner is lighted and extinguished automatically.

The "open" type of geyser requires to be fixed above the fitting to be supplied with hot water, whereas the "sealed" pattern

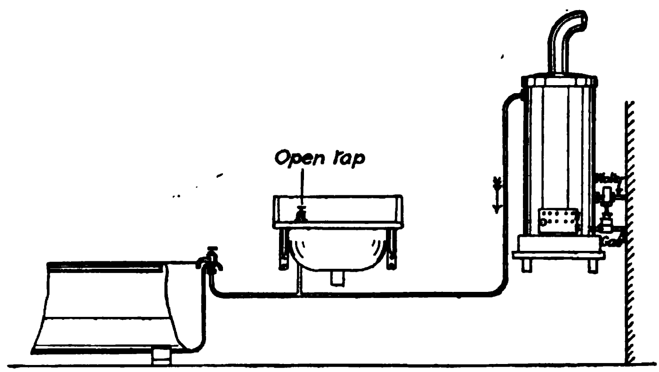

FIG. 181.—Geyser supplying Bath and Lavatory.

may be fixed either above or below the fittings. Moreover, *one or more fittings can be supplied* from a sealed type of heater.

Fig. 181 shows a sealed pattern geyser with pipe arrangements for supplying a bath and lavatory.

The "hot" tap in the latter fitting has a fixed top; also, a clear way is maintained through it. The bath tap discharges at a lower level, and will take the whole of the discharge of hot water from the geyser. When hot water is required in the lavatory basin, the bath tap is turned off previous to starting the geyser to work.

Geysers using oil fuel are useful in country districts where gas supplies are not available. For shooting-boxes, golf-clubs, hostels, etc., they can be adopted with advantage.

They are easily managed and controlled, and differ from gas-heaters only in the method of lighting and the necessity of periodic renewals of the oil fuel in the reservoir.

Petroleum oil is generally used. It is vaporised by the

FIG. 182.—Baxendale's Oil Geyser.

burners before ignition occurs; therefore no wick is necessary. To start the burner a small quantity of methylated spirit is ignited, the heat from which vaporises the petroleum.

Fig. 182 shows a view of a "sealed" pattern geyser, which uses oil fuel.

Geysers can be obtained for connecting to existing hot-water services. It should be remembered, however, that they are not nearly so economical as range boilers or independent boilers consuming coal.

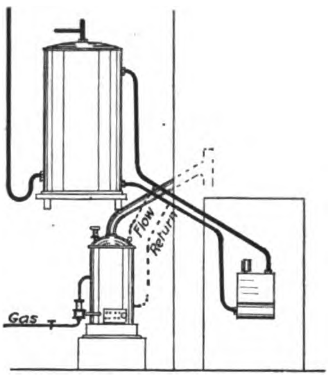

FIG. 183.—Connection of Gas Heater to existing Circulation Pipes.

They act as independent boilers, but when lit they do not require further attention if a thermostatic valve be provided.

Fig. 183 shows a geyser attached to the circulation pipes of an existing hot-water service. The fumes from the burner are conveyed into the kitchen flue.

It is inadvisable to fix stopcocks on the circulation pipes, but if these are considered to be necessary, then a safety valve must be fixed on the geyser.

Fixing of Geysers.—The chief points to be observed are—The entire removal of the products of combustion from the burners into the open air; the necessity for an adequate gas pressure, and for a gas-supply pipe of sufficient diameter.

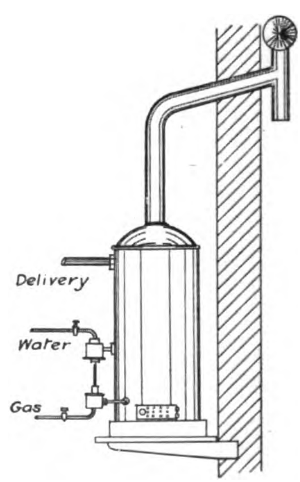

FIG. 184.—Mode of fixing Geyser.

The size of the geyser also requires consideration. The duty required of the geyser will decide the diameter of the pipe necessary for use with the same.

The products of combustion which emanate from the burners, particularly those of the Bunsen type, are detrimental to health. Moreover, in a closed bathroom they may asphyxiate the occupant whilst he is engaged in bathing. The chief products of the combustion of coal-gas are CO_2 and CO; both of these gases are invisible and odourless. Although

a fairly high percentage of CO_2 (*i.e.* 2 to 3 parts per 100 parts of air) is not fatal, yet a much smaller percentage of CO will cause asphyxiation.

Fig. 184 shows a geyser *in situ* with the ventilation pipe discharging into the open air. To guard against down-draughts a suitable cowl must be attached to the upper end.

Geysers must not be fixed without a ventilation pipe, as shown, or one of similar efficacy.

The heating value of coal-gas varies in different districts; the effective duty per unit volume is influenced by the quality of the gas, and the type and condition of the burner.

One cubic foot of coal-gas employed under reasonably good conditions in an efficient apparatus will raise the temperature of 10 lbs. of water through a range of from 40° to 50° F.

Assuming that 35 galls. of hot water at a temperature of 100° F. be required for a bath, and that the temperature of the cold water entering the geyser be 50° F., also that the price of gas is 2s. 6d. per 1000 cub. ft.—

35 galls. of water = 350 lbs.
1 cub. ft. of coal-gas when burnt will raise the temperature of 10 lbs. of water from 50° F. to 100° F.;
∴ 35 cub. ft. of coal-gas when burnt will raise the temperature of 350 lbs. of water from 50° F. to 100° F.

1000 cub. ft. cost 30*d*.

$$35 \quad " \quad " \quad \frac{30 \times 35}{1000}$$

= one penny (approx.)

To prevent sudden rushes of gas through the meters when the geysers are in full use, suitable "gas governers" should be fixed on the gas main on the house side of the meter.

CHAPTER XII

WARMING OF BUILDINGS BY OPEN FIRES, STOVES, AND APPARATUS USING STEAM OR HOT WATER

In countries where the temperature often falls below freezing-point it is necessary to warm artificially, buildings that are occupied by human beings.

The following modes of heating are adopted:—

1. Open fires and open or closed stoves, using coal, coke, gas, or oil fuel.
2. Apparatus using steam, air, or water as heat-conveying media.

In the first case the source of heat is contained in each room. In the second case a common centre is provided for the heating apparatus from which the heat is conveyed through pipes or conduits by means of one of the media mentioned.

The open fire or stove warms the room by direct radiation. The air is warmed by contact with the walls and objects in the room, and where stoves are used the air is warmed partly by contact with their heated surfaces.

The advantages of the open fire are:—

1st. It has a bright and cheery appearance.

2nd. It is contended that radiant heat from an open fire is healthier than that from stoves or pipes.

3rd. The chimney flue is a valuable exit shaft. The heated gases and products of combustion pass up the flue at a high velocity and extract the vitiated air from the room by induction.

4th. In many cases the fire is utilised for warming water for domestic purposes and cooking food, in addition to warming the room.

The disadvantages are:—

1st. The removal of ashes; also, occasional down-draughts of smoke cause dirt and inconvenience in the rooms.

2nd. The fuel economy is very low, 15 to 25 per cent. only of the fuel consumed is converted into effective work.

3rd. In large buildings the cost of attending to the many fires that are required is excessive.

4th. The heat is not distributed equally throughout the room; generally the portions which require the most heat receive the least amount. This is especially so in large rooms, portions of which are situated 15 to 20 ft. from the fire.

This inequality of heating by an open fire is due to the fact that the relative value of radiant heat varies inversely as the square of the distance from the fire. Thus an object 4 ft. from the fire will receive four times the quantity of heat that is received by a body 8 ft. from the fire.

The closed stove has a higher fuel economy than the open fire. If the stove be fixed in the centre of the room the heat is distributed more equally to all parts.

The chief disadvantages of the closed stove are:—

1st. Where slow combustion is resorted to there is some risk of CO escaping into the room in sufficient quantity to cause ill-health to the occupants.

2nd. The organic particles in the air are charred by contact with the heated surface, and impart an unpleasant smell to the air in the room.

3rd. The air is drier, and it apparently loses certain invigorating properties that are usually experienced in the air of rooms warmed by open fires.

In this country small dwellings are invariably warmed by the open fire method, but in countries where coal is much dearer than it is here, the closed stove is adopted.

Large houses having many rooms with the necessary halls, passages, and landings, cannot be economically or efficiently warmed by either the "open fire" or "closed stove" method.

This remark applies to all classes of public buildings, including theatres, places of worship, schools, public institutions, hotels, etc.

The warming of these buildings can be carried on with

efficiency and economy by adopting the second method, in which the heating is accomplished from one central station, the heat being distributed to all parts by either hot air, hot water, or steam.

Where hot air is used it is passed directly into the rooms at a comparatively high temperature, and mingles with the colder air. The walls, etc., are warmed principally by contact with the heated air.

Steam or hot water is circulated in pipes or conduits through the substance of which heat is imparted to the walls, furniture, and air of the various rooms.

Systems that utilise hot water or steam as heat-conveying media are:—

1. Low-pressure hot water.
2. High-pressure hot water.
3. Atmospheric or low-pressure steam.
4. High-pressure steam.

In addition to these there are several patented systems which utilise a combination of steam and water.

The advantages of these systems, as compared with the open fire or stove, are:—

1st. Higher fuel economy.

2nd. The heat may be distributed in exact accordance with requirements.

3rd. The temperatures of all portions or any particular portion of a building can be regulated to meet varying demands.

4th. The air entering the building can be warmed before it reaches the occupants, thereby avoiding the inconvenience and discomfort of cold-air currents.

5th. The control of the furnace or boiler fire is a simple matter, and the attention required is considerably less than for open fires; moreover, the dust and dirt caused by boiler firing is confined to the boiler apartment, usually in the basement.

The disadvantages are:—

1st. The initial cost of installing a system.

2nd. The air in the heated rooms apparently loses some of its invigorating qualities.

3rd. Wall surfaces, curtains, and other hangings immediately

above the pipes or radiators become coated with dust, carried by currents of warm air that are caused by the heated surfaces of the pipes.

This disadvantage can be minimised by using deflectors on the pipes or radiators, which will divert the air-currents towards the centre of the room.

Before considering the systems in detail, a critical examination will be made of *the losses of heat that are incurred in the warming of buildings;* also, estimates will be made of the heating surfaces necessary to compensate for the loss of heat under various conditions.

When the temperature of the air outside a building is lower than that of the air inside, heat will pass by conduction through the walls, floors, ceilings, and windows, from the inside to the outside. Moreover, the incoming air will require to be warmed, also, the air leaving the building will have a higher temperature than the outside air.

From this statement it will be seen that to maintain a building at a desirable temperature it is necessary to provide radiating surfaces which will emit a quantity of heat equal to the amount that will be lost through walls, windows, floors, and ceilings, and by the escape of vitiated air, when a maximum difference of internal and external temperatures obtains.

Formulæ are available for determining the heating values required under certain conditions. The use of several of these under identical conditions will produce results which vary as much as 100 per cent. Few if any formulæ are applicable to a wide range of conditions; moreover, they are usually cumbersome and but imperfectly understood by those interested in the subject.

If the general basic principles be thoroughly understood, the subject may be handled in a more confident and successful manner by the practical engineer. Moreover, they may be successfully applied to the variety of conditions usually met with in ordinary practice.

The effective quantity of heat emitted in a given time from a unit area of heating surface is governed by:—

1. The character and position of the surface.
2. The difference in temperature of the radiating surface and the surrounding bodies, including the air.
3. The velocity of the air passing over the heated surface.

Authorities differ as regards the amount of heat which is emitted per unit area. Values of from 1·3 to 2·3 B.Th.U. per square foot per hour for each degree difference between the temperature of the steam or water and that of the room are given.

The difference in the values obtained is due chiefly to the different conditions (*i.e.*, sizes of pipes and temperatures of water or steam, etc.) under which the experiments were carried out.

Under normal working conditions it is not possible to accurately determine the amount of heat that will be emitted in each case. All calculations are, at the best, only approximations, the degree of accuracy of which is influenced by the consideration given to the minor details and special features of individual cases.

In the calculations undertaken in the following pages, it is assumed that 1 sq. ft. of radiator surface will emit 1·6 B.Th.U. per hour, for each degree of difference between the temperature of the room and that of the water or steam contained in the pipes.

The following table gives the rate of transmission of heat through various surfaces in B.Th.U. per square foot for 1° difference between the internal and external temperatures:—

Nature of Material.	B.Th.U. transmitted per hour for each Degree Difference.
Glass (single window) . .	1·1
„ (double „) . .	0·5
Brick wall, 4½ ins. . . .	·5
„ 9 „ . . .	·4
„ 14 „ . . .	·35
Ceiling, near roof . . .	·32
„ with large air space .	·17
Floor (concrete) . . .	·52
„ (wood)	·18
Doors	taken as wall surface

Note.—·019 B.Th.U. is required to raise the temperature of 1 cub. ft. of air through 1° F.

It is essential to adopt a minimum temperature for the

outside air, to facilitate the determination of the heating surface necessary to make good the heat lost.

In this country the air does not remain for long periods at temperatures below 25° F.; therefore this figure can be taken as the minimum temperature of the air in calculating the loss of heat from buildings.

The air in buildings is maintained at different temperatures, according to the character of the structure and the nature of the work carried on therein.

Higher temperatures are required where the work is of a sedentary character than in the case of occupations involving manual labour.

Places of worship and buildings where large numbers of people congregate for periods of from two to four hours, require special consideration. If the requisite temperature for comfort be obtained previous to the buildings being occupied, it may be raised to an uncomfortably high degree during occupation by the heat evolved from the occupants. To minimise this unpleasant development, the initial temperature of the interiors of such buildings should not exceed 58° F.

The following table gives the average temperatures that are desirable in different buildings:—

Type of Room or Building.	Desirable Temperature.
Workshops (where manual labour is employed)	50° to 55° F.
Factories (other than cotton or woollen factories)	50° ,, 55° F.
Churches and public buildings	58° rising to 62° F.
Schools	55° to 60° F.
Dwelling-houses	58° ,, 62° F.
Halls and passages	65° ,, 70° F.
Hospitals	55° ,, 65° F.

If it be required to determine the amount of heat lost from a building, the dimensions of which are given, the following procedure may be adopted.

Example.—A workshop 80 ft. × 30 ft. × 12 ft. with a flat ceiling, and all walls exposed to the outer air, is to be maintained at a temperature of 55° F. when the temperature of the

outer air is 25° F. The windows occupy an area of 600 sq. ft. The air is to be changed three times per hour. Find the loss through various channels in B.Th.U. per hour.

Volume of air required per hour $= 80 \times 30 \times 12 \times 3 = 86{,}400$ cub. ft.

1 cub. ft. of air requires ·019 B.Th.U. to raise its temperature through 1° F.

Therefore 86,400 cub. ft. require $\cdot019 \times 86{,}400(55 - 25) = 49{,}248$ B.Th.U.

Net wall surface $= 2(80 \times 12) + 2(30 \times 12) = 2040$ sq. ft.

1 sq. ft. of 9-in. wall transmits ·4 B.Th.U. per square foot per hour for each degree difference between internal and external temperatures.

Therefore 2040 sq. ft. will transmit per hour $2040 \times \cdot4(55 - 25) = 24{,}480$ B.Th.U.

1 sq. ft. of glass will transmit per hour 1·1 B.Th.U. for each degree difference.

Therefore, 600 sq. ft. of glass will transmit per hour $600 \times 1\cdot1(55 - 25) = 19{,}800$ B.Th.U.

Assuming the floor to be of wood, the loss per hour will be:—

$$80 \times 30 \times \cdot18(55 - 25) = 12{,}960 \text{ B.Th.U.}$$

The loss through the ceiling will be:—

$$80 \times 30 \times \cdot17(55 - 25) = 12{,}240 \text{ B.Th.U.}$$

Total loss per hour:—

	B.Th.U.	
Air	49,248	
Walls	24,480	
Glass	19,800	
Floor	12,960	
Ceiling	12,240	
	118,728	B.Th.U.

In the determination of the radiating surface necessary to supply this quantity of heat several factors must be considered, the principal one being the average temperature of the water or steam in the pipes.

In Low-pressure Hot-water Systems the average temperature will rarely exceed 170° F. In low-pressure steam systems using steam at from 3 to 5 lbs. pressure per square inch, an

average temperature of 215° F. will be obtained, and in high-pressure hot-water or steam systems the temperature will vary according to the pressure.

Assuming that a low-pressure hot-water apparatus is to be used, the total radiating surface required to provide 118,728 B.Th.U. per hour

$$= \frac{118728}{1 \cdot 6(170 - 55)} = 646 \text{ sq. ft. (approx.)}$$

In the case of systems using steam at atmospheric pressure, the average temperature of the pipe walls will not exceed 205° F.

Other factors which influence the quantity of heating surface required are:—

Direct and Indirect Heating Surfaces.—Direct heating consists of pipes or radiators fully exposed in the rooms. Heat is imparted to the room by radiation from the heated surfaces to the walls, etc., and by convection currents caused by contact of the air with the pipes or radiators.

Indirect heating consists of pipes or radiators that are placed in channels, troughs, conduits, air ducts, or chambers through which air is delivered to the apartment or building. A portion only of the radiant heat is available for warming the building, and in consequence a greater amount of heating surface is required.

The additional quantity necessary will be governed by local conditions. Where the heating surfaces are in the immediate vicinity of the rooms 50 to 60 per cent. must be added to the quantity determined, but when they are placed some distance from the rooms an addition of 75 per cent. will be required.

Ventilating Radiators designed to warm and conduct the fresh air into buildings necessitate an addition of 25 to 35 per cent. to the estimated heating surface when fixed inside the rooms.

Walls that have a northerly aspect, also rooms possessing ill-fitting doors or windows, require extra heating surface.

If a building is heated intermittently, additional heating surface of from 30 to 40 per cent. will be necessary to raise the temperature to a requisite degree within a reasonable time.

CHAPTER XIII

LOW-PRESSURE HOT-WATER APPARATUS

THE low-pressure hot-water mode of warming buildings consists in having a boiler to which one or more pipe circuits are attached. The boiler is usually fixed at the lowest point of the system.

The pipes, etc., are kept fully charged with water by means of a tank fixed above the highest portion of the circuits.

It will thus be seen that the pressure in any part of the system is due to the height of the free surface of the water in the tank, above the point of observation.

The maximum temperature obtainable in all parts of a system, other conditions being satisfactory, will depend upon the head of water, but under the best conditions the average temperature of the heating surfaces will rarely exceed 200° F., and will almost invariably be 170° F.

The latter temperature is generally accepted as the standard for heating surfaces in low-pressure hot-water systems.

The arrangement of pipe routes will be governed by local conditions.

It is essential that all pipe circuits shall have a definite "rise" from the boiler to the highest points where provision must be made for the escape of air.

Dips or traps should be avoided where possible. A satisfactory circulation under such conditions is in some instances difficult to obtain.

All changes of direction should be made by the use of bends, and tees of the curved pattern should be used in preference to those of the rectangular type.

The sizes of the pipes in different parts of the system must

be carefully adjusted to ensure an equal distribution of hot water through the various circuits.

The mode of connecting the various branch pipes to the principal mains must also receive attention. The branch circuits on lower floors of buildings are often unsatisfactory, owing to faulty pipe connections.

An important point which must always be borne in mind, is the advantage gained by conveying the hot water to the highest points in the system by the shortest routes possible.

The alternative pipe routes in Fig. 185 explain this point. The flow pipe in the circuit P M rises to the point T, and, after a short vertical length is traversed, enters the boiler by the

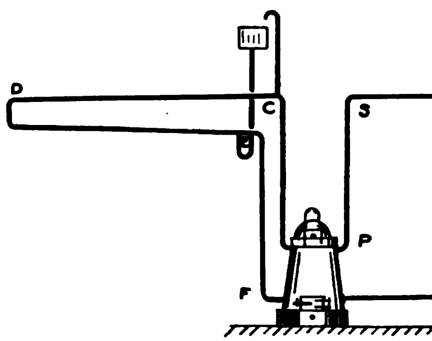

FIG. 185.—Two Methods of Pipe Arrangements for Low-pressure Hot-water Heating.

inclined return pipe M. The water loses heat whilst travelling from the boiler to the point T, particularly in the long length of inclined pipe, in which the water will be denser than in the vertical pipe P S. Again, the water in the pipe T Q will be hotter than in the pipe M. If the pipes are arranged as shown in circuit G F, the denser water in the pipe C D will assist the circulation instead of acting against it; also, the column of water in E F will be denser than that in T Q; consequently the circulation will be accelerated.

These two features often occur in hot-water systems, and advantage should be taken of them to increase the efficiency of the work.

Radiating Surfaces consist of Pipes, Coils, and Radiators. The pipes used for this purpose vary in diameter

from $1\frac{1}{2}$ ins. to 4 ins. The smaller pipes have larger heating surfaces for a given capacity than pipes of larger diameters.

The relative capacities of pipes vary as the squares of their diameters, whereas the circumferences vary directly as their diameters.

Thus a 4-in. pipe will have four times the capacity of a 2-in. pipe of equal length, *i.e.*,

$$4^2 : 2^2 = 16 : 4 = 4 \text{ to } 1,$$

but its circumference will be only twice that of a 2-in. pipe, *i.e.*,

$$\pi 4 : \pi 2 = \frac{\pi 4}{\pi 2} = \frac{2}{1}$$

Small pipes are neat in appearance, and can be used with advantage where economy of space is desired.

The comparatively larger quantity of hot water contained in pipes of large diameter prevents appreciable fluctuations of temperature occurring owing to irregular stoking. This is a distinct advantage in the case of glasshouses in which the temperature has to be maintained above freezing-point during winter nights.

Coils and Radiators.—The two terms are synonymous, although the former is the older word and is generally applied to massed heating surfaces, the major portion of which are horizontal or have a slight inclination. The latter is a more modern term. It is applied to groups or batteries of tubes or heating surfaces the bulk of which are arranged vertically.

Fig. 186 shows one type of "coil," which consists of a

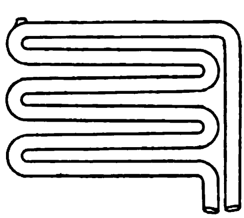

Fig. 186.—Coil Radiating Surface.

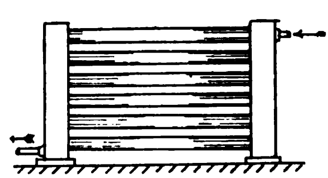

Fig. 187.—Coil with Box Ends.

continuous tube. It is not so efficient as the other pattern, shown in Fig. 187.

There are other patterns consisting of spiral coils of

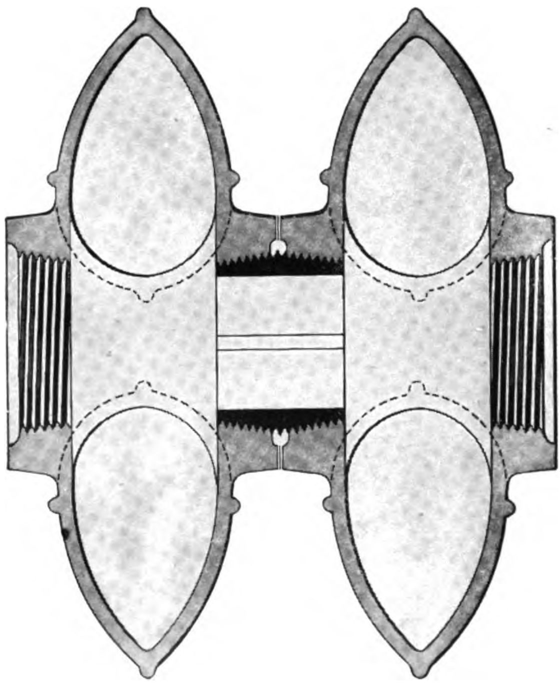

Fig. 188.—Screwed Nipple Connection for Radiator.

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wrought-iron pipe, also several columns of horizontal pipes connected to vertical ends or boxes.

Radiators are generally more efficient than coils. The vertical tubes facilitate the downward flow of the cooled water; moreover, the tubes are made in various shapes, the majority of which combine a neat appearance with a maximum heating surface in a minimum space.

The tubes may have plain or embossed surfaces. Radiators of all sizes and shapes to fit any position are obtainable.

Pipe Surfaces and Radiators compared.—For horticultural work pipes of from 3 to 4 ins. diameter are more suitable than radiators, but for private houses and public buildings radiators have a distinct advantage. They have a neater appearance and the heating surface can be concentrated in the most effective positions, such as beneath windows, near to doors, on landings, and in entrance halls, with ornamental results.

The circulation pipes can be placed out of sight if necessary, or they can be fixed just above the floor. In the latter case the heat which is emitted from their surfaces should be taken into account when estimating the radiating surfaces.

Cast-iron and copper are used in the manufacture of radiators. Copper is only adopted where appearance is to be obtained regardless of expense. In cast-iron radiators the tubes are formed with one or more vertical waterways which communicate top and bottom with a common conduit.

The tube sections are coupled together by means of left- and right-hand threaded taper nipples, or by tapered plain barrel nipples.

In the former case the sections are pulled together during the screwing up of the nipples, whereas in the latter case the sections and nipples are placed in position and then forced together by means of a powerful screw or hydraulic clamp.

Fig. 188 shows a horizontal section through a screwed nipple connection.

The top and bottom waterways are prepared for pipe connections on both ends of each radiator, thus allowing some latitude in the manner of connecting them to the circulation mains.

Fig. 189 shows a double column plain tube radiator suitable for use with steam or hot water.

Fig. 190 shows a similar radiator, but with ornamental tubes.

Where a larger quantity of heating surface is desired without a material increase in the size of the radiator, the four-column radiator shown in Fig. 191 can be used.

Where lack of space will not permit a wide-tube radiator to be fixed, one similar to that shown in Fig. 192 will be found advantageous.

The extreme projection of this radiator will not exceed 3¾ ins., including 1-in. space between the wall and the radiator. Sections can be coupled together, and the heating surface thus increased to meet the requirements of any position.

Radiators for use in Hospitals must be as plain as possible; also, there should be no corners, angles, or recesses where dust and dirt can lodge.

Fig. 193 shows an example of the "fixed" pattern. Sufficient space must be allowed between the wall and the radiator to allow of easy access for cleaning all parts of the wall and radiator.

An improved pattern for hospital use is shown in Fig. 194. The top and bottom of one end of the radiator are connected to two swivels, which allow it to be swung outwards for cleaning purposes.

The bottom swivel has two connections, one for the flow and the other for the return pipe. The water is conveyed to and from the radiator through the two conduits formed in the elbow shown in section in Fig. 195. The flow water is delivered into the first vertical tube and the return is received into the lower conduit from the waterway at the bottom of the radiator.

A satisfactory circulation is maintained in the radiator by this mode of connection. A strong wall bracket of cast-iron bolted securely in position supports the fitting and prevents disturbance of any of its parts.

The radiators described are of the "direct" type for use in rooms, halls, passages, or landings.

Ventilating Radiators are of two types—the "direct pattern" and the "indirect pattern."

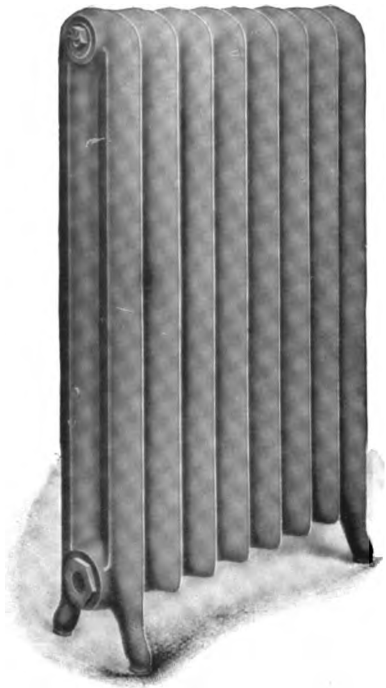

FIG. 189.—Plain Two-column Radiator.

FIG. 190.—Ornamental Two-column Radiator.

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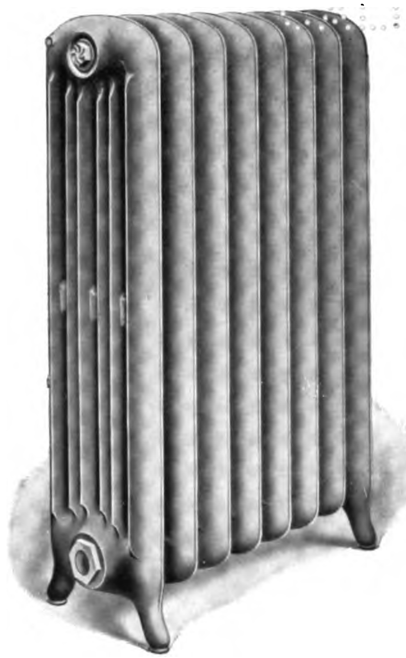

Fig. 191.—Four-column Radiator.

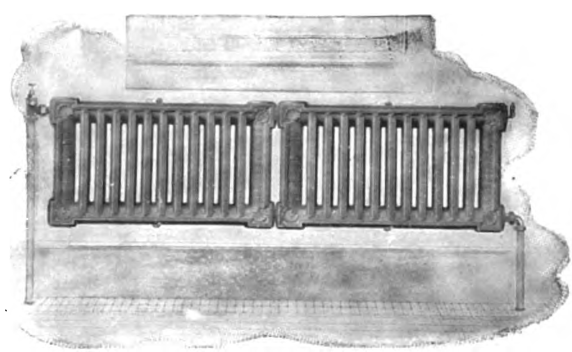

Fig. 192.—Narrow Tube Radiator.

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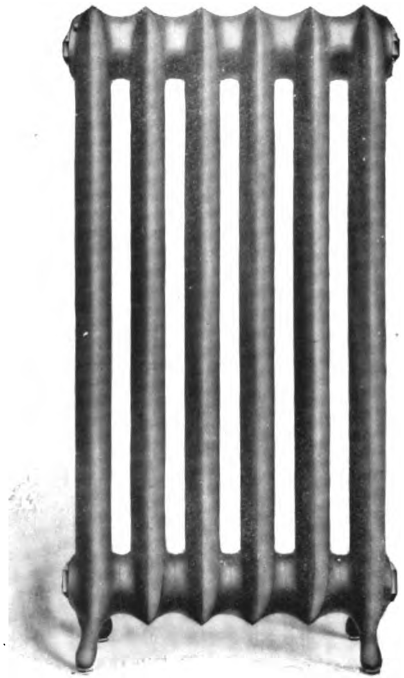

FIG. 193.—Hospital Radiator, Fixed Pattern.

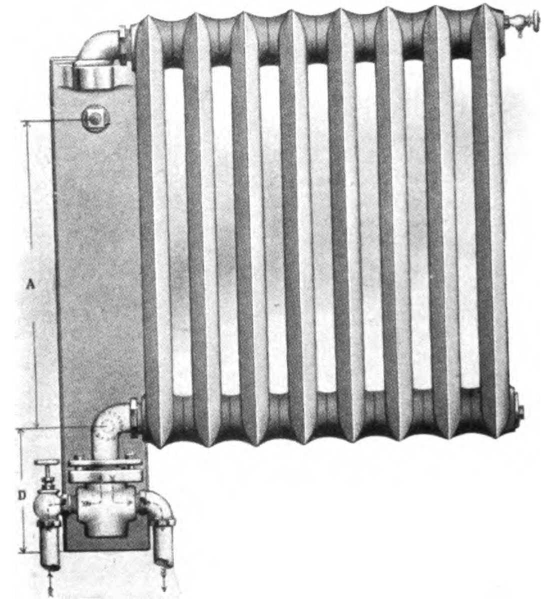

FIG. 194.—"Astro" Hospital Radiator, Hinged Pattern.

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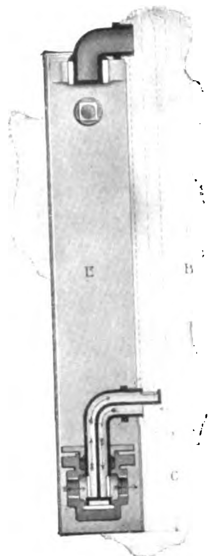

Fig. 195.—Hospital Radiator (section through).

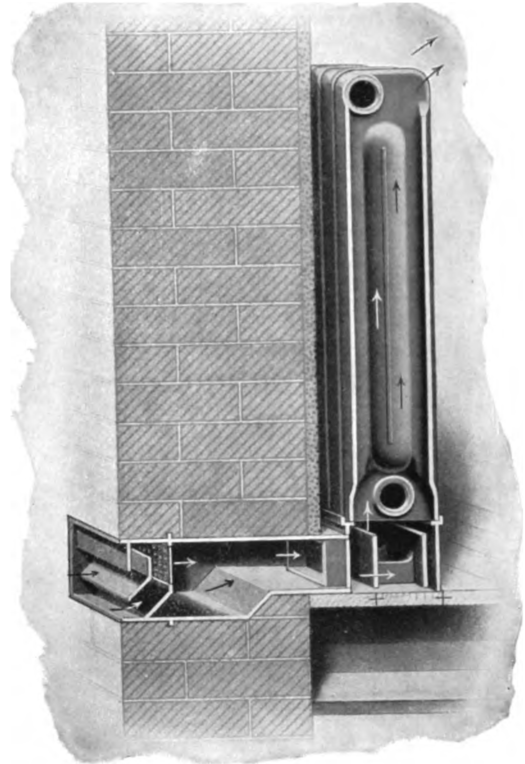

Fig. 196.—"Marshall" Ventilating Radiator.

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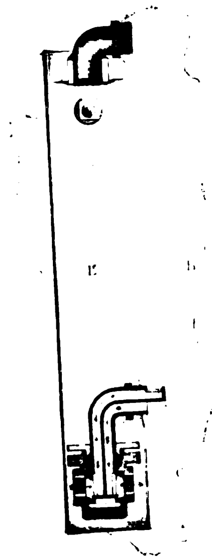

Fig. 195.—Hospital Radiator (section through).

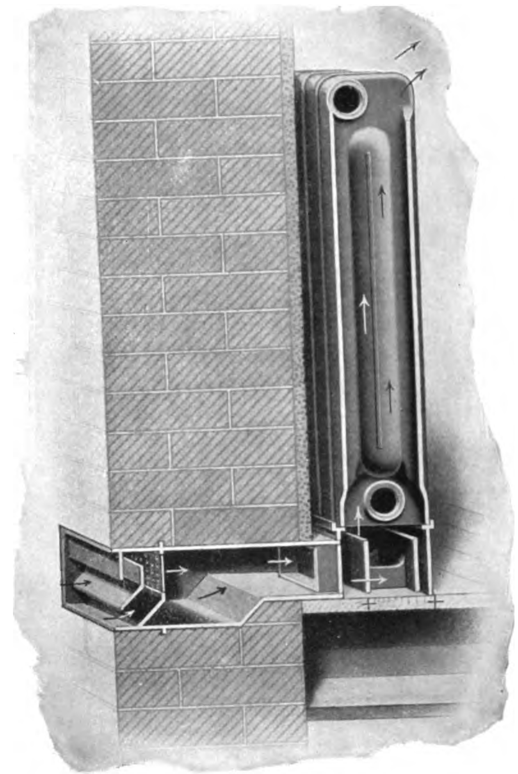

Fig. 196.—"Marshall" Ventilating Radiator.

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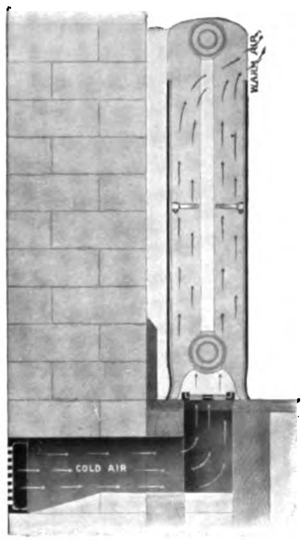

Fig. 197.—Ventilating Radiators.

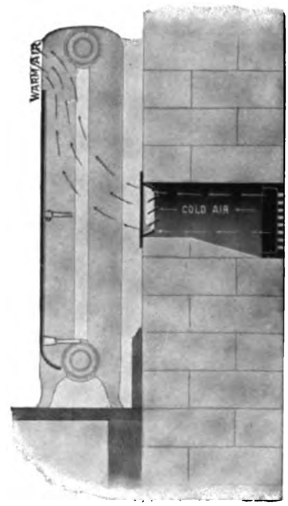

Fig. 198.—Ventilating Radiators.

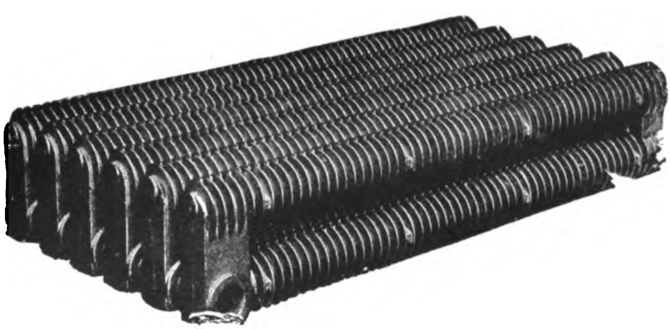

Fig. 199.—Indirect Ventilating Radiators.

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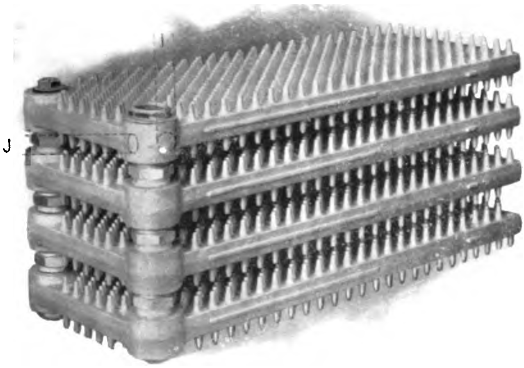

FIG. 200.—Indirect Ventilating Radiators.

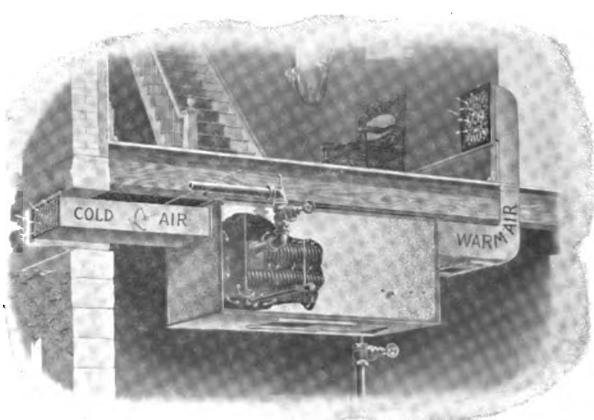

FIG. 201.—Indirect Ventilating Radiators *in situ*.

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The former are fixed in the rooms, whereas the latter occupy specially constructed chambers in the walls or beneath the floors, and are entirely out of sight.

There are many forms of each type.

In the "direct" pattern the tubes may be formed with air ducts through which the air is delivered into the room. Fig. 196 shows a part section and view of a radiator with air passages in the vertical tubes. The air is admitted to the base through an aperture in the wall.

Fig. 197 shows an ordinary radiator of the "direct" type equipped with baffle plates to act as a ventilating radiator. The cold air passes between the baffle plates and is warmed by contact with the tubes before entering the room.

The radiator shown in Fig. 198 has baffle plates attached to the front only. The air is admitted to the centre of the radiator at the back.

Valves are generally used on the cold air inlets to control the air supply.

Indirect Radiators are constructed so that a maximum heating surface is contained in a minimum space.

Figs. 199 and 200 show two types of indirect radiators. The gills on the tubes in Fig. 199 increase the heating surface, as also do the pins cast on the plates in Fig. 200.

Fig. 201 shows the application of indirect radiators for the warming of an entrance hall and dining-room.

The owners of large private houses often object to direct radiators as being unsightly and out of harmony with the surroundings. Indirect radiators can be used with advantage under such conditions. For small rooms two warm air tubes will usually be sufficient, but in the case of a large room a radiator should be fixed at each end immediately beneath the floor. The cold air ducts leading to these should be large enough to supply the whole of the warm air ducts leading to the rooms with an adequate quantity of fresh air.

The cross-sectional area of short ducts should be equal to $1\frac{1}{2}$ sq. ins. per square foot of heating surface.

For air ducts of considerable length a comparatively greater area is necessary. Two to $2\frac{1}{2}$ sq. ins. per square foot of heating surface is usually allowed. The larger quantity is intended to compensate for the loss due to friction in long air ducts.

To prevent loss of heat, the interior of the radiator chamber should be lined with tinplate and surrounded with a 1-in. layer of slagwool. The outer walls of the chamber may be formed of tongued-and-grooved timbers 1 in. thickness.

Pipe Arrangements for Circulating the Water are known as follows:—

1. The one-pipe system.
2. The two-pipe system.
3. The overhead or drop-pipe system.

The One-pipe System consists of one or more single-pipe circuits, which traverse the parts of the building where heating surfaces are required. The main pipes are of uniform bore throughout.

It is suitable for buildings of one or two storeys, or in positions where numerous branch circuits of short length are desired.

Small buildings of one or two storeys may be heated by radiators connected to one circuit.

Fig. 202 shows a line diagram of a simple one-pipe system

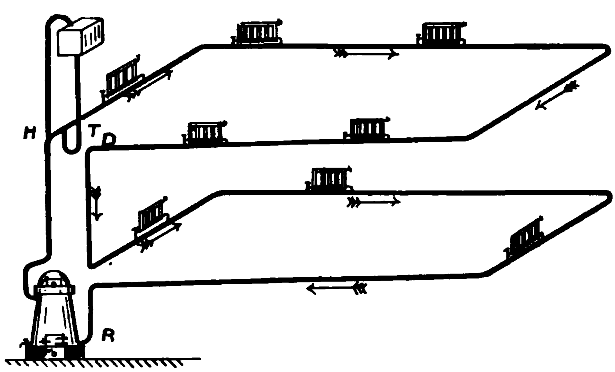

FIG. 202.—One-pipe System for Low-pressure Hot Water.

consisting of a single circuit, to which the radiators on the ground and first floors are connected.

The flow pipe is taken vertically to the point H. This is the highest part of the system. An air pipe is provided at this point for the escape of air which is released from the water.

From this point the pipe has a gradual declination to D, whence a vertical length supplies the radiators on the ground floor. The return pipe joins the boiler at R.

It will be observed that the portion of the pipe from H to R descends; therefore the radiators are all connected to the return pipe.

This is a better method than one that is often adopted in which the flow pipe rises from H to D. The water in this length is constantly cooling, and is therefore denser than that in the vertical flow pipe. Thus, instead of assisting the circulation, as would obtain if the pipe declined from H to D, it retards it.

The chief disadvantage of the single circuit is the uneven heating of radiators throughout the circuit. Those nearest to the point H will be warmest, whilst those near to R will be much lower in temperature. A difference of from 10° to 20° F. is often experienced where this method is adopted.

The position of the tank in relation to the pipes is immaterial if it be 1 or 2 ft. above the highest radiator. The cold supply pipe is sometimes taken directly to the boiler, but such a course is not always necessary. It may be connected at any convenient point in the circuit. A trap should be formed on the pipe as shown at T, Fig. 203, to prevent local circulation between the tank and the heating mains.

Fig. 203 shows a modification of the previous example, which will give a more equal distribution of hot water to the radiators on the two floors.

The flow pipe F is taken directly to the ground floor, and a horizontal branch B supplies the first floor circuit. This arrangement provides a satisfactory flow of water through the lower circuit.

It should be remembered that where two or more floors are to be supplied from a vertical flow pipe, there is some risk of the lower floor circuits receiving less than the necessary quantity of hot water.

There is not often any difficulty experienced in obtaining a satisfactory circulation in the higher branches owing to the greater value of the "circulating head" which produces the motion of the water in the pipes.

Branch circuits should not be connected to the vertical flow pipe by horizontal branches. The vertical pipe or "riser" must be continued to each floor as a direct lead, and the pipe for the upper floor branched from it as shown at B, or a special fitting may be used.

If the return pipe from the ground floor be connected to the return pipe from the upper floor at the point E, the lower circuit will have a sluggish circulation. The "circulating head" causing motion under such conditions would be very

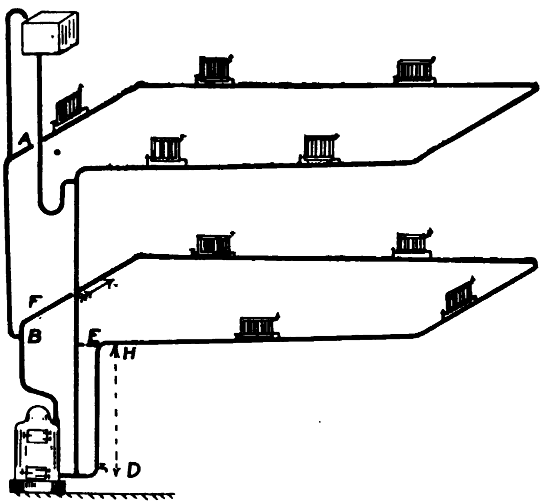

FIG. 203.—One-pipe System with Two Circuits.

small, but by continuing the return vertically for 3 or 4 feet, the additional column H D will accelerate the flow.

An air pipe, valve, or cock should be attached at F in addition to the one on the upper floor at A.

Fig. 204 shows another modification of the one-pipe system. One or more circuit mains are provided in the basement storey, and the radiators on the ground and first floors are supplied by risers connected with these mains. The secondary circuits practically embody the "two-pipe" principle.

If the radiators be fixed in tiers and there is an objection to pipes laid around the rooms either above or beneath the floors, this system can be adopted with advantage. It should be noted, however, that, compared with the previous example, there are a large number of risers.

The radiators on the ground floor may have separate flow and return pipes, or they can be connected to the risers that supply the radiators on the upper floor.

If the latter method be adopted, a special fitting should

be used on the inlets to the radiators. Moreover, the top inlet T must be used in the case of the lower radiators, but the flow pipe can enter the bottom inlet of the upper radiators. The return pipes from the former should be continued vertically for a short distance before joining either the circulating main or the return from the upper radiators.

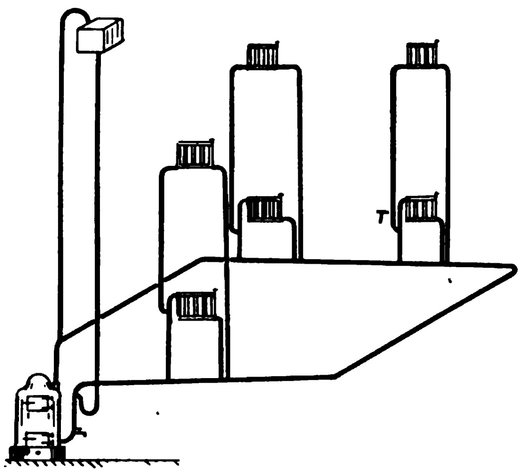

FIG. 204.—One-pipe System with Secondary Circuits.

Dips or traps in the main circuits or branch circulations should be avoided as far as possible. If the pipes are laid above the floors, and, to complete a circuit it is necessary to cross one or more doorways, dips will be indispensable.

Fig. 205 shows a line diagram of a one-pipe system with two dips or traps formed in the ground floor circuit. A departure from the ordinary mode of connecting the flow pipe of the ground floor circuit is adopted. Instead of connecting this pipe at the point F, it is branched at a point from 6 to 8 ft. higher at C. The additional head C F will readily overcome the retardation due to the cooler water having to be forced up the small vertical heights at X X.

A sluggish circulation would result if the flow were connected at F. The vertical distance between F M would provide only a small "circulating head," whereas that obtainable between the points C and M, will be ample for the purpose.

Similarly, efficient results could be obtained by connecting

the flow pipe at F if the vertical distance of 6 or 8 ft. could be obtained between M and N. The cooler water in this pipe would pass quickly towards the boiler and displace the warmer water through the flow pipe.

If the flow pipe be connected at F, and the return be joined to the vertical pipe from the upper flow, as indicated by a dotted line at M, there would be little or no movement of water in the lower circuit.

At the points marked X, air pipes, automatic valves, or air

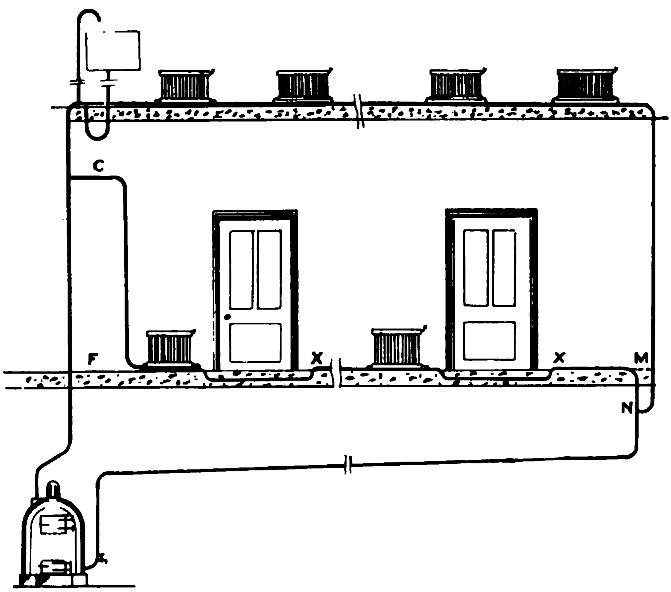

Fig. 205.—One-pipe System with Dips.

cocks must be provided, otherwise an accumulation of air may occur which would tend to reduce the flow of hot water through the circuit, or entirely stop it.

The one-pipe system will yield satisfactory results if the circuits are comparatively short, and the pipe routes properly arranged. Also, there is less risk of "short" circuiting occurring.

A satisfactory circulation can be obtained where several dips or traps occur if one circuit only is used. Fig. 206 shows a line diagram of the pipe routes of a heating system

installed in a building. The floors of one portion are about 2 ft. below corresponding floors in other parts of the building. The flow pipe at A is the highest point in the circuit. Air pipes or other devices are provided at the points marked X.

When working under normal conditions the temperature of the water in the column C D was 25° to 35° F. lower than the temperature at the point A.

The radiating surfaces provided on the ground floor under

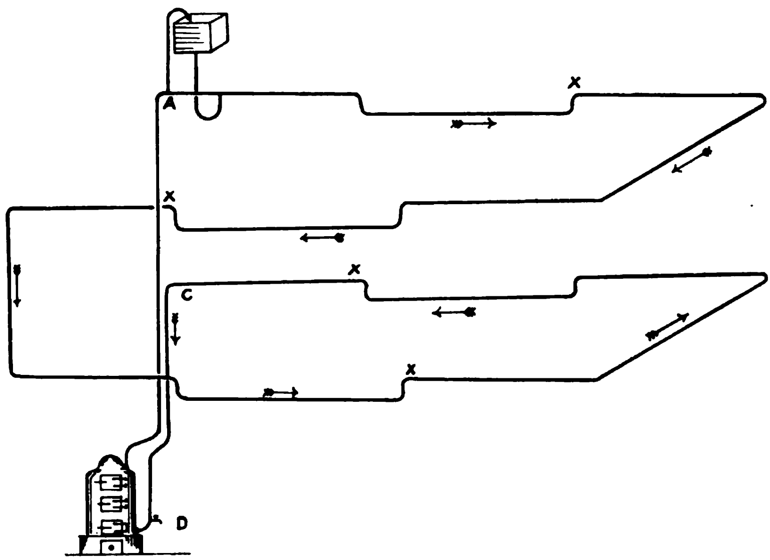

FIG. 206.—One Circuit with Several Dips.

such conditions will require to be greater in area for the same duty than those on the upper floor.

The difference in temperature stated does not represent the average temperature differences of the radiators. This did not exceed 20° F.

In workshops, warehouses, etc., pipes are sometimes used for radiating purposes on account of cost. Fig. 207 shows a system for a three-storey building. It is a modification of the one-pipe system. Pipes of cast-iron are used, the diameter of which may be either 3 or 4 ins. according to requirements. The flow pipe to each floor is treated in the manner previously described. The points marked A are the highest parts of the

respective circuits. One air pipe may be used to receive the connection from each floor as shown, or a by-pass of ⅜-in. brass tube, indicated by the dotted line B, will serve the same purpose, the air eventually passing through the pipe A C.

The mode of connecting together the return pipes will facilitate the flow of water through the lower circuits. The

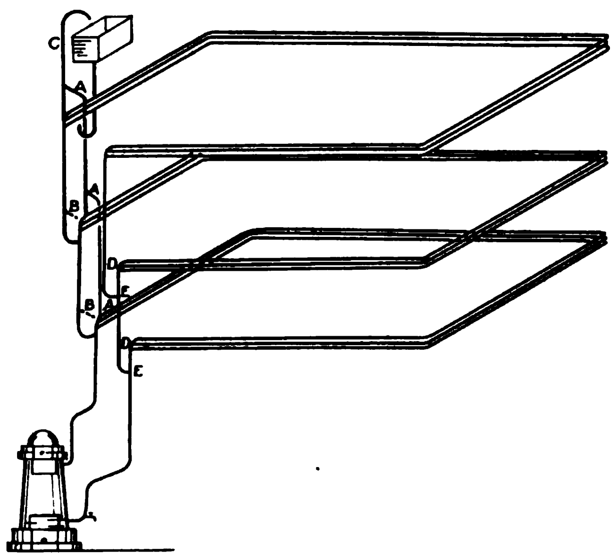

Fig. 207.—One-pipe System with Pipe Radiating Surface.

column of water in D E will be colder than that in the flow pipe at A, and will tend to increase the circulating head in each of the lower circuits.

The Two-pipe System differs from the one-pipe system inasmuch that in the former each circuit is composed of two pipes, one acting as the flow and the other as the return pipe.

This system is suitable where pipes are used for the radiating surface. It is occasionally adopted in connection with radiator schemes, but unless care is exercised, satisfactory results are difficult to obtain. Moreover, it is more expensive than the one-pipe system.

Where long circulating mains are necessary, it is contended that better results are obtained by the use of the two-pipe system. If radiators are adopted, they should

be connected entirely to the flow pipe, otherwise short circuiting of the current of hot water is liable to occur.

Fig. 208 shows a simple example of the two-pipe system. Two circuits are provided, one on each side of the boiler. It will be observed that the radiators in the circuit A are each connected to the flow and return pipes of the circulating mains, as at X Y. If the mains are of considerable length and have not a good inclination, there will be some risk of the hot water making a short circuit through the by-pass which is provided by the radiator flow and return pipe connections to the circulating mains.

This can be avoided by connecting the inlet and outlet

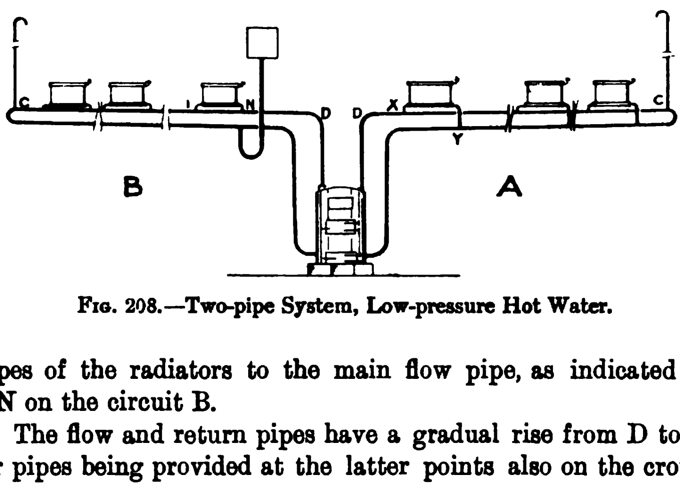

Fig. 208.—Two-pipe System, Low-pressure Hot Water.

pipes of the radiators to the main flow pipe, as indicated at I N on the circuit B.

The flow and return pipes have a gradual rise from D to C, air pipes being provided at the latter points also on the crown of each radiator.

Fig. 209 shows the plan and sectional elevation of a two-pipe system which is in use for warming a large single-storey building.

A separate circuit is provided on each side, the pipes having a gradual rise from A to B.

The same results could be obtained by use of the one-pipe system, as indicated in Fig. 210. A separate flow pipe is provided for each side, the highest points of which are A A, where air pipes are attached. The returns B B are taken below the floor, and join the pipe C, which returns the water to the boiler.

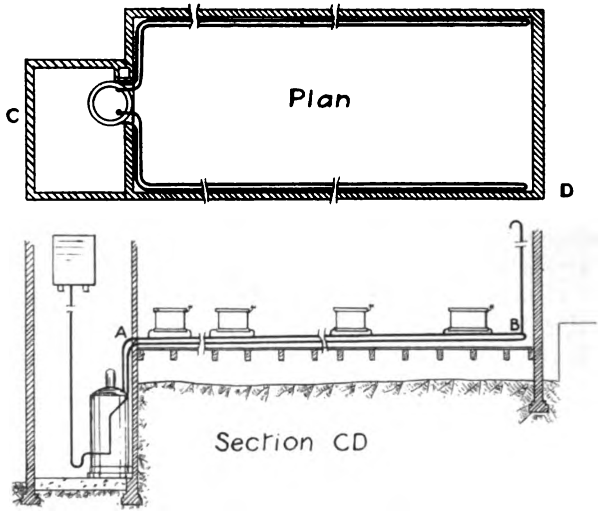

Fig. 209.—Two-pipe System, Plan and Sectional Elevation.

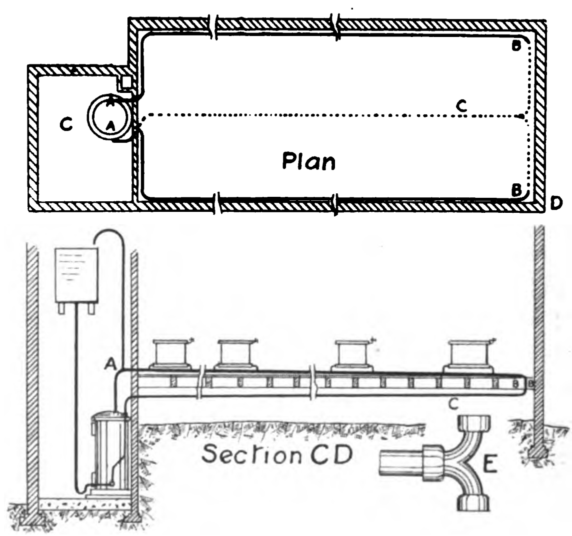

Fig. 210.—One-pipe System for same Building.

The special tee-piece indicated by the detail E should be used where the pipes B B join the pipe C to equalise the delivery of water from the two circuits.

The cross-sectional area of C must be equal to the combined areas of the two pipes B B.

The Overhead or Drop-pipe System is suitable for use in high buildings with radiators, especially if the latter are arranged in tiers. It consists of one or more flow pipes that are led to the topmost storey of the building. From the highest points of the flow pipes or "risers," inclined branch pipes are distributed to all parts where groups or tiers of radiators are arranged.

Fig. 211 shows this system applied to a four-storeyed building. The flow pipe should be continued from the boiler to the highest point by the shortest route. Radiators are not connected to this pipe, but where feasible it should be covered with a non-conductor of heat, so that the water may be delivered at a maximum temperature to the various drop pipes.

Each tier of radiators has a separate drop pipe, to which the inlet and outlet pipes of the radiators are connected.

The mode of connecting the latter with the drop pipe requires some consideration. The top inlets must be used in conjunction with circular tees.

The return pipes should be continued vertically for a distance of from 2 to 3 feet before joining the drop pipe, as shown at A B (Fig. 211). The short vertical column of cooled water in A B will accelerate the rate of flow through the radiator.

An alternative method, using the connection in the opposite end of the radiator as indicated at C D, is stated to produce a more equal distribution of the water throughout the radiator than the other method, but the advantage gained is so slight that it is of no practical importance.

The drop pipes are collected in an inclined return pipe.

It will be observed that "swan necks" or "offsets" are formed on all the long lengths of vertical pipes, as at X X, etc. Movement takes place freely at these points during expansion and contraction of the vertical pipes, thereby obviating the risk of fracture. In all similar cases this

principle should be adopted, especially where flow pipes are continued vertically for some distance above the boiler.

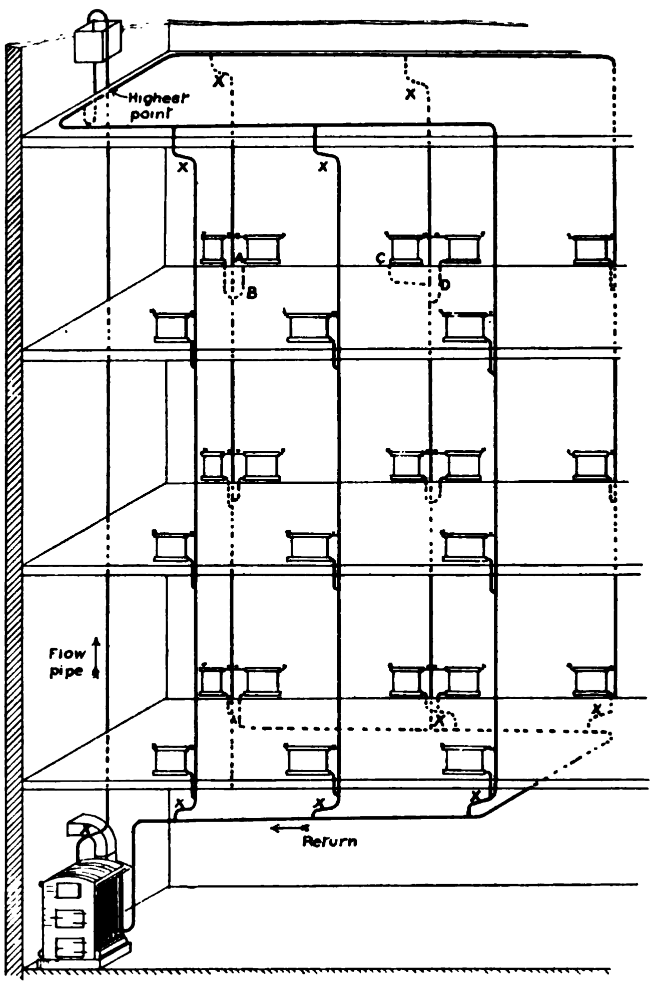

Fig. 211.—Overhead or Drop System, Low-pressure Hot Water.

In a building which is heated by the drop-pipe method, exception may be taken to the vertical pipes passing through certain rooms. A modified arrangement will then be necessary to obviate this objection. Fig. 212 shows a loop formed on

the one-pipe principle for supplying the radiators in the apartments A and B. The pipe is laid beneath the floor, and has a gradual fall from C to D and from E to the short vertical length. It should be remembered that this pipe will probably have a larger radiating surface to maintain than the other drop pipes; therefore its diameter should be greater.

In most cases one air pipe fixed at the head of the flow pipe will be sufficient for the whole system. The radiators

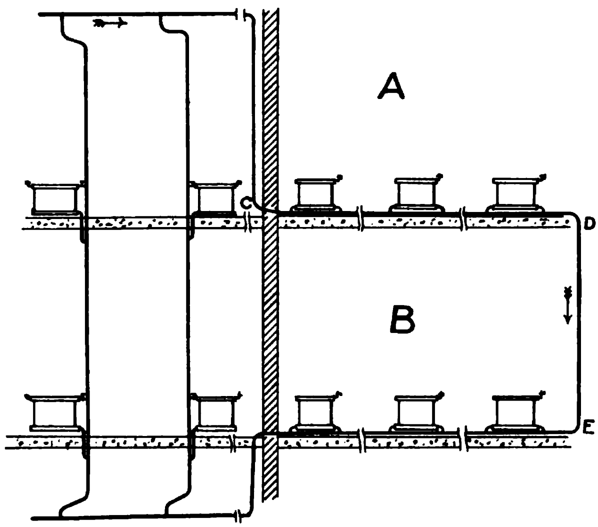

FIG. 212.—Overhead or Drop System (modified arrangement).

usually have an aircock, or an automatic valve, attached at the crown.

If it is imperative, owing to structural causes, that the distributing pipes be dipped before reaching the drop pipes, provision for the escape of air must be made at each of the high points or crowns thus formed.

For high buildings of several storeys, the drop-pipe system is more satisfactory than the others. A quick flow is obtainable through the vertical pipes, owing to the comparatively high value of the circulating head.

The flow pipe should be large enough to meet the demands

of the whole of the drop pipes, otherwise the circulation through one or more of these will be somewhat sluggish.

In one-storey buildings, the interiors of which considerably exceed 20 ft. in height, as is the case with churches, chapels, and similar structures, the comparatively large wall area, frequently of stone, renders the efficient warming of such buildings a matter of some difficulty.

To prevent down-draughts of cold air, caused by the cooling of the heated air by contact with the higher parts of the walls, it may be necessary to employ a pipe circuit in the upper portion of parts of the building.

In the case of a church having a clerestory immediately above the central nave, provision will have to be made to counteract the cooling effects of the clerestory windows, walls, and roof to prevent cold down-draughts.

The upper system of pipes will also aid the work of ventilation, by maintaining a high temperature of the air near the exits.

The chief disadvantage of the use of hot-water systems in such positions is the risk of freezing during frosty weather, when the apparatus is not working. If it is not considered desirable to maintain the boiler fire continuously, the difficulty can be overcome by arranging for the pipes in the higher circuit to be emptied during periods of frost, or a low-pressure steam system may be installed to warm all parts of the building.

The Porches and Entrance Halls of Churches and Chapels should be provided with an abundance of radiating surface, so that the large volume of air which invariably rushes into the building when the porch and outer doors are opened simultaneously, will be warmed and therefore cause no unpleasantness to the occupants.

Each outer window should have a radiator fixed immediately beneath it, to which fresh air is admitted through a conduit at the floor-level similar to Fig. 196. If the radiator in this position would otherwise project unduly into the building, a recess should be formed beneath the window to receive the radiator. This arrangement will counteract the cooling effect of the windows.

Double glazing of the windows is resorted to in certain

cases. If radiators cannot be conveniently applied, this will improve existing faulty conditions, but will not entirely eliminate them.

An important factor which should receive particular attention in the warming of buildings, is the necessity for lighting the boiler fires and maintaining a steady consumption of fuel, from one and a half to three days before the building is occupied. This applies especially to places of worship during periods of frost.

The connection of radiators to the circulating mains requires special notice. Where the radiators are fixed directly above the horizontal mains, tees of the curved, lipped, or injector pattern can be used.

The injector nozzle on the flow pipe is turned towards the current of hot water, whilst that on the return pipe points in the opposite direction. A portion of the hot water is diverted by this arrangement, and a steady flow through the radiator is obtained.

The chief objections to the injector tee are the resistance offered to the flow by the projection of the nozzle in the main pipe, and the delivery of cooled water from the return connection at the top of the stream of hot water.

If the circulating mains are of large diameter, the first objection is not of great importance. If the return enters the side of the main, the cooled water will tend to sink to the bottom of the pipe, and a stratum of hot water will be available in the higher portion of the pipe for the other radiators.

By using an injector tee in a vertical position on the main, the cooler water from the radiator mixes with the warmer water in the pipe, and thereby materially reduces its temperature.

In all cases the returns from radiators should enter the side of the main when the flow and return are connected to one pipe.

If radiators are connected to vertical subsidiary mains, a distributing or circular tee should be fixed on the lower radiators to cause a more equal distribution of the flow. Also, the top connections should be used for the flow pipes, and the return pipes should be continued vertically some 2 or 3 ft. before joining the subsidiary return pipe.

Radiators that are fixed near to the horizontal circulating mains should not be connected to the vertical subsidiary mains, but should join the former pipes by separate branches of sufficient capacity.

It is advisable to fix a control valve on each radiator to facilitate the varying of the radiation surface to meet the requirements of atmospheric conditions.

Globe valves are not suitable for the purpose. Full-way valves of the Peets' type or the angle pattern (Fig. 221) can be used with advantage.

Each radiator must have an arrangement for releasing air which may accumulate.

Air pipes are best for this purpose, although air cocks give equally good results when they receive periodic attention.

The **relative values of radiator and pipes surfaces** must be considered when designing a scheme. Pipes that are slung from the ceiling with free air-space around them have a higher coefficient of radiation per unit area than if fixed near the floor.

Again, radiators have a less radiation coefficient than pipes. The coefficient varies also with the type of radiator. If the sections or columns are packed closely together, less efficiency will be obtained than in the case of radiators in which the columns are farther apart.

An increase in the number of water columns or tubes per section causes a decrease of efficiency per unit area of radiating surface. Single column radiators have a higher coefficient than those formed of double columns, etc.

The opposite radiating surfaces in the sections of a radiator do not lose as much heat per unit area as the freer surfaces that are fully exposed to the room. This is explained by the fact that radiant heat is emitted in straight lines from warmer bodies to those in the vicinity having a lower temperature.

The freedom with which air may circulate over and around the radiating surfaces also influences the amount of heat emitted in a given time. Thus ventilating radiators require a comparatively higher boiler-power to maintain their efficiency than those of the non-ventilating pattern of equal area.

The following table gives the approximate relative values

of pipe and radiator surfaces. Pipes fixed near to the floor are taken as the standard:—

Radiating Surface.	Relative Value of 1 sq. ft.	Approximate relative Areas which will emit the same Quantity of Heat in Unit Time.
Pipes fixed near floor	100	1·00
1-column radiator	95	1·05
2- „ „	90	1·10
3- „ „	85	1·20
4- „ „	80	1·25
Ventilating radiator (direct pattern) .	75	1·45
„ „ (indirect pattern)	60	1·65

The comparative figures in the third column are average values.

CHAPTER XIV

PIPES AND FITTINGS, INCLUDING VALVES, AUTOMATIC AIR VALVES, SUPPLY TANKS, ETC.

PIPES of wrought-iron are generally used where the diameter does not exceed 2 ins.

Although a large quantity of gas-strength wrought-iron tube is used for heating purposes in the lower class of work, it is not as satisfactory as the steam-strength tube. The latter has a much longer life and is generally more reliable.

Screwed joints are adopted for connecting the pipes and fittings. The cut ends of wrought-iron pipes must be rhymered, to ensure a full bore and clear way, before they are screwed together.

Elbows should be avoided where possible, as they materially restrict the flow of water.

Bends should be used where changes of direction are required.

Tees are either of wrought or of malleable iron. The latter have a neater appearance than the former and give equally good results in practice.

Fig. 213 shows a curved pattern tee which should be used on pipes 2 ins. and less in diameter.

Fig. 214 shows a double junction or cross of the curved pattern. The curves cause a more gradual deviation of the flow from the main to the branches than obtains in the case of a rectangular pattern tee.

When the vertical main terminates at two horizontal branch mains, the tee shown in Fig. 215 should be used.

Where branches to radiators are unavoidably placed in unfavourable positions, the supply of hot water to the radiators can be augmented by using distributing tees similar to that

shown in Fig. 216. The projecting lip will divert a portion of the main flow into the branch pipe. This pattern of tee should not be used where an equal distribution of the flow is obtainable by a normal arrangement of pipes.

Fig. 213.—Curved Tee-piece.

Fig. 214.—Curved Cross-piece or Four-way.

Fig. 215.—Double Branch.

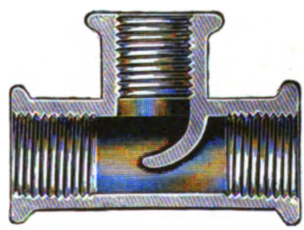

Fig. 216.—Distributing Tee.

Cast-iron pipes are generally used for circulating mains that are more than 2 ins. in diameter. They are invariably used in diameters of 2 to 4 ins. for horticultural and other work where pipe surface is adopted for radiating purposes.

Cast-iron pipes are cheaper than those of wrought-iron; also, they are not as easily corroded, and they emit more heat per unit area under similar conditions than pipes of wrought-iron.

The joints on cast-iron pipes are made in various ways. The spigot and socket type is most commonly used. The jointing materials consist of (1) gaskin and a mixture of red and white lead; (2) gaskin and rust cement; (3) gaskin and Portland cement.

In the first kind, plain gaskin is steeped in the lead mixture and is stemmed tightly into the socket in layers or rings

alternating with rings of a stiff paste of red and white lead. The socket is entirely filled in this manner, or a space of 1 in. is left which is filled with rust cement to complete the joint.

In the second kind of spigot and socket joint the gaskin may be either plain or tarred. The former is easier to manipulate, but is quickly decomposed by the water. From three to six rings of gaskin are tightly caulked into the socket and the remaining space is filled with rust cement.

The latter is composed of clean cast-iron borings mixed with either sal-ammoniac or finely powdered sulphur, or both, and moistened with water before use.

Care is necessary in mixing the cement. If excessive quantities of either sulphur or sal-ammoniac are used, undue expansion of the cement occurs some time after the joints are made, sockets are cracked or burst, causing inconvenience and expense.

Not more than 2 ozs. of sal-ammoniac must be added to 56 lbs. of borings.

If a quick-setting cement be desired, 2 ozs. of finely powdered sulphur is added to the above.

The third kind consists of two or three rings of plain gaskin soaked in Portland cement and well caulked into the socket, the remaining space being filled with Portland cement mixed to a very stiff paste. This joint gives excellent results if care be exercised during the making of the same.

Expansion Joints are adopted in some cases in preference to the ordinary spigot and socket pattern.

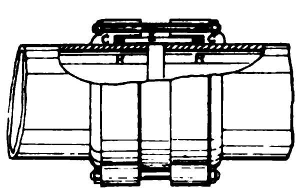

FIG. 217.—Jones' Expansion Joint.

The former can be disconnected and replaced with comparative ease, whilst the latter require to be cut or broken to effect alterations or repairs. The chief objection to their use lies in the rubber rings with which the joints are invariably made.

These are liable to decay, and thus cause leaky joints.

Fig. 217 shows Jones' expansion joint. It is formed by a sleeve of cast-iron, E, which is passed over the ends of two pipes and held in position by the two clamps C C. Two rubber

rings, R R, are placed between the ends of the sleeve and the clamps before the latter are bolted together. Socketless pipes are used with this joint.

It will be found very useful for connecting two spigot ends together instead of using a thimble and the ordinary jointing materials.

Fig. 218 shows an expansion joint by the Beeston Co. The pipes are socketed, and have bolt lugs cast on each socket. A loose clamp is passed over the spigot, and is bolted to the socket with rubber rings between the two surfaces.

An expansion joint can be inserted with advantage on all long lengths of pipe.

Fig. 219 shows a cast-iron, socketed double tee-piece with injector flaps for diverting the water into the branch pipes. This is a useful fitting on a large horizontal main.

Pipe-fixing.—This part of the work requires to be carefully carried out to ensure success to the scheme.

Pipes fixed in any position must have permanent and unyielding supports. Expansion and contraction must be provided for by the use of expansion joints or loops where such are necessary.

If slight falls only are obtainable in the various horizontal routes, these must be carefully apportioned to avoid the formation of air-pockets, which would materially reduce the cross-sectional area of the water flow.

For pipes of large diameter fixed horizontally, anti-friction rollers attached to special brackets are often used for supports.

Where pipes pass through apartments that do not require to be warmed, the pipes should be covered with a poor conductor of heat to prevent undue loss of heat from the system.

The determination of the Sizes of Pipes necessary to adequately serve a given area of radiating surface will be influenced by the conditions under which they are to be fixed. Greater efficiency is obtained by the use of pipes that are too large than with those that are too small. This is especially noticeable where a large number of radiators are connected to a single circuit. If the main is too small the radiators furthest from the boiler will be supplied with water at a temperature

of from 20° to 30° F. lower than that of the water which enters the first radiator on the circuit.

The difference in temperature desired between the water in the flow and return pipes will also materially affect the sizes. The difference usually provided for is 20° to 25° F., but if less than this is required, larger circulating mains will have to be used.

In the case of long circuits, larger pipes will be required for supplying a given surface than would be necessary for shorter circuits. Also, the height of the circuit will have some influence upon the diameter of the pipes. The higher the circuit is carried above the boiler, the greater will be the circulating head available for causing movement of the water through the pipes.

Fig. 220 gives the sizes of pipes required to carry given values of radiating surfaces.

It will be observed that the vertical pipes or "risers" are comparatively smaller than the horizontal pipes. The velocity of flow through the latter is not so great as that which occurs in the "risers."

The various radiation figures given should be taken as the maximum.

The smallest diameter of pipe used for radiator connections should be $\frac{3}{4}$ in. One-inch diameter pipes will be sufficient for a radiator having an area of 80 sq. ft., but for radiators of from 80 to 150 sq. ft. in area, $1\frac{1}{4}$-in. pipes should be used.

Valves.—It is advisable to fix a valve on the flow pipe to each radiator. Also, branch circuits can be better controlled and the flow of hot water more equally distributed if a valve be fixed on the flow pipe of each branch circuit.

For wrought-iron pipes Peets' valve or valves of the full-way pattern must be used.

For radiators the angle valve shown in Fig. 221 will give satisfactory results. It is compact, and provides a full clear way for the water flow.

Throttle Valves are usually adopted in the case of cast-iron pipes. They consist of a disc of brass or iron attached to a spindle, which is inserted in a specially prepared body. They are simple and effective for pipes of large diameter. Several types are shown in Fig. 222. The discs may be removed from

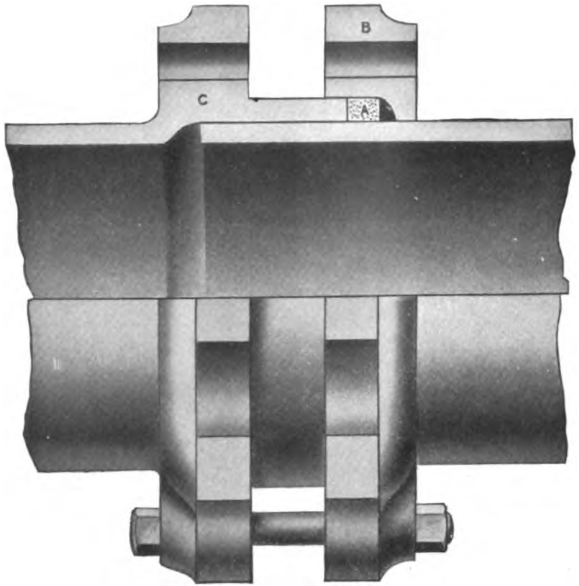

Fig. 218.—Beeston Expansion Joint.

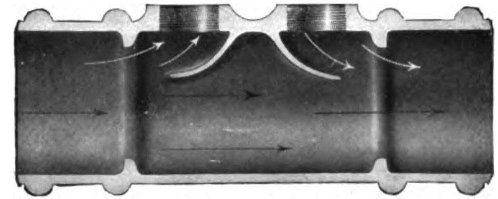

Fig. 219.—Cast-iron Tee, Distributing Pattern.

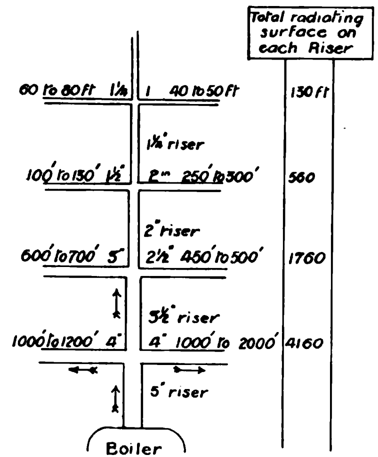

Fig. 220.—Diagram of Sizes of Pipes.

Fig. 221.—Angle Valve for Radiator.

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the body of the valve without disturbing the pipes if repairs are necessary.

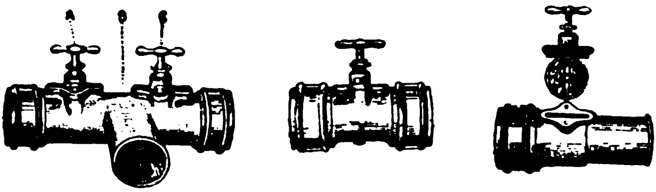

FIG. 222.—Throttle Valves.

Aircocks are generally fixed on radiators where air pipes would be inconvenient. They should be made of gunmetal, and must be strong and serviceable. Where there is risk of mischievous interference, aircocks with detachable keys should be used.

Periodic attention is necessary to keep the radiators free from air.

Air Pipes may be of lead, iron, copper, or brass. Where possible they should be fixed in preference to other devices. They are entirely automatic and need no attention.

Automatic Air Valves are often fixed on radiators, especially where a large quantity of air accumulates and an air pipe cannot be used. In all cases they should be provided with a cock for shutting off the water when repairs are necessary.

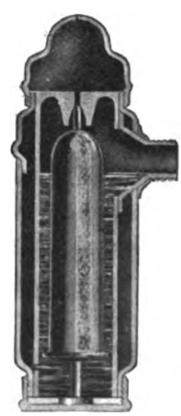

FIG. 223.—"Norwall" Automatic Air Valve.

Fig. 223 shows a section of the "Norwall" air valve. The metal cylinder enclosed in the shell is floated so that it closes the exit when the inner chamber is filled with water. When air accumulates in the upper portion, the water recedes and the metal cylinder falls, leaving the exit passage open. The air escapes and the water again forces the cylinder against the exit.

Each system must have a draw-off tap attached to the boiler or to one of the return pipes for emptying purposes in case of repairs or alterations.

It is not advisable to empty the apparatus during warm weather, but if it is not required at certain periods in the

winter it will be necessary to empty it to prevent damage to the pipes, boilers, and radiators by the freezing of their water-content.

Supply Tanks may be of wood lined with lead or copper, or they may be of cast-iron. They are generally fixed in the most out-of-way position some 2 or 3 ft. higher than the highest radiator. Tanks may be supplied with water by hand, or they may have a service pipe attached to them. The latter method is preferable.

When deciding the capacity of the tank, it should be remembered that water expands when heated, and unless provision is made in the supply tank for the increase of volume the tank will overflow on each occasion of a material fluctuation of the temperature of the water in the apparatus.

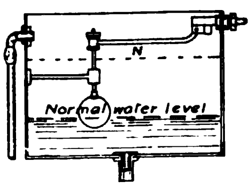

FIG. 224.—Supply Tank for Low-pressure Hot-water Heating System.

When the temperature of water is increased from 4° C. (maximum density temperature) to boiling-point, an increase in volume of from 4 to 5 per cent. occurs.

Provision for expansion to the extent of 4 per cent. of the total capacity of the apparatus should be provided in the storage tank, in the space between the normal water-level when the apparatus is cold and the overflow level.

Fig. 224 shows the arrangement of ball tap and overflow which will provide for expansion without permitting the water to overflow. The ball tap is fixed near to the top of the tank, and is provided with a vertical rod which may be regulated by the locking nuts N to give the required space.

The ball tap is often fixed near to the bottom of the tank, but this is not good practice. Moreover, it does not comply with the requirements of waterworks authorities.

The Cold Supply Pipe between the tank and the apparatus need not exceed ¾ in. diameter for small systems, or 1 in. diameter for large systems.

A trap is formed on the pipe to prevent local circulation between the tank and the apparatus.

CHAPTER XV

BOILERS FOR LOW-PRESSURE HOT-WATER SYSTEMS—RATING—EFFICIENCY, FLUES, ETC.

THERE are many patterns of boilers in use in connection with hot-water apparatus. They may all be classed under the following heads:—

1. Boilers requiring brick enclosures.
2. Independent boilers that are self-contained and do not require any brickwork.

Before considering the various forms or patterns of each type of boiler, it is advisable to enquire into the modes adopted for estimating their heat-transmitting values.

The Efficiency Ratio of a boiler may be based upon two principles:—

1st. The average number of British Thermal Units which will be transmitted per hour through 1 sq. ft. of boiler surface.

2nd. The percentage calorific value in British Thermal Units which the boiler will absorb from the fuel used.

It is quite possible to have a comparatively high theoretical efficiency if the first principle is alone considered. A boiler may be designed to transmit an average of 10,000 B.Th.U. per square foot per hour, but its efficiency on the second count will probably be relatively low, due to the high temperature of the waste products and heated gases in the flues.

Again, a boiler may be so constructed as to absorb 60 per cent. of the calorific value of the fuel, but the average transmission of heat through the whole of its surface may not exceed 2000 B.Th.U. per square foot per hour.

The factors that influence the amount of heat transmitted in a given time per unit area are:—

1st. The ratio of the direct to the indirect heat-absorbing surfaces.

2nd. The relative positions of such surfaces, whether they are horizontal, vertical, or inclined.

3rd. The grate area.

4th. Type of fuel used.

5th. The degree of attention paid to cleaning of boiler surfaces.

6th. Height and cross-sectional area of chimney.

The first three are of the greatest importance.

Direct Surfaces absorb radiant heat from the fire in addition to that which they obtain from the heated gases. Their values vary in the same boiler according to their nearness to the primary source of heat, *i.e.* the fuel. One square foot may transmit 20,000 B.Th.U. per hour, whereas a similar area more remote from the fire will not transmit more than half that quantity.

Indirect Surfaces absorb heat only from the gases as they pass to the chimney. If the surfaces are broken or irregular, or are perpendicular to the direction of the flow of the heated gases, a higher rate of heat transmission is obtained than in the case of even surfaces arranged parallel to the direction of the flow.

Again, these surfaces become coated with a deposit of soot, which acts as a non-conductor of heat and reduces the rate of transmission.

No reliable estimate can be given which will apply in all cases to the heating value of indirect surfaces, but it may be stated that under the best conditions an average of not more than 500 B.Th.U. per square foot per hour will be transmitted. Under adverse conditions this may be reduced to 200 B.Th.U.

It will thus be seen that, other conditions being equal, the greater the ratio of direct to indirect surface, the higher will be the average amount of heat transmitted per unit area.

Where the indirect surface is more than from three to four times the direct surface, the average rate of heat transmission is comparatively low.

The Grate Area should be proportioned in accordance with the heating surfaces of the boilers. It is ridiculous to expect a boiler to absorb more heat than is obtainable from the maximum quantity of fuel which can be burned in a given time on the grate area provided.

The amount of coal which can be burned per unit area of grate per hour varies with the type of boiler, the kind of grate, height of chimney, and the kind of fuel. It is stated that from 4 to 16 lbs. may be burned per square foot per hour in ordinary low-pressure hot-water boilers.

The average generally taken is 7 or 8 lbs. Not more than 50 per cent. of this is converted into effective work. In many cases only 35 to 40 per cent. is absorbed by the boiler surfaces.

The calorific values per pound of different fuels are given on p. 229.

Improper or careless firing is often responsible for low efficiency in boilers. In a well-fired boiler the best results are obtained by frequent firing, using small quantities of fuel at each operation. The fuel should be served in pieces not larger than $1\frac{1}{2}$ ins. cube, and should be kept to the front of the furnace.

Attention to the heating surfaces of the boiler also has a considerable influence upon the results. Frequent removals of the sooty deposit will materially increase their efficiency.

Although coal of good quality has a higher calorific value per unit weight than coke, the latter is more suitable than the former, owing to the small amount of soot which *coke* gives off during combustion; consequently the boiler surfaces are cleaner.

The height of the chimney and the cross-sectional area of the same have a direct bearing upon the amount of fuel which will be consumed.

Tall chimneys cause a higher velocity of the products of combustion and air through the boiler than short chimneys; consequently the fuel is burned more rapidly.

The minimum inside measurement of a short chimney should be 9 ins. by 9 ins., but tall chimneys should be not less than 12 ins. by 12 ins.

Rating of Boilers.—The usual methods of rating adopted by the manufacturers of boilers consists of a statement of (1) the length of 4-in. pipes, or the square feet of radiating surface which can be maintained by the boiler in question at a temperature of from 170° to 180° F. when the outer air is at 30° F.; or (2) the total British Thermal Units which the boiler is considered to be capable of transmitting per hour.

There is no absolutely satisfactory method by which the heating value of a boiler can be accurately determined.

A reasonable degree of accuracy can be obtained by taking as a basis the amount of fuel which can be consumed on a square foot of grate surface. If the total grate area in square feet be multiplied by this value and 40 per cent. or 50 per cent. of effective work assumed, the total British Thermal Units available can be ascertained.

Assuming that an average of 8 lbs. of fuel (coal or coke) are burned per hour on each square foot of grate, and that the calorific value of the fuel = 9000 B.Th.U. per pound; also, that only 40 per cent. of this is brought into effective use: then the total British Thermal Units per hour per square foot of grate

$$= 8 \times 9000 \times \frac{40}{100}$$

Example.—A boiler has a grate area of 8 sq. ft.; how many square feet of radiator surface will it maintain at 180° F. when the air in the room registers 55° F.?

Total B.Th.U. absorbed by boiler per hour

$$= 8 \times 8 \times 9000 \times \frac{40}{100} = 230400$$

1 sq. ft. of radiator surface emits 1·6 B.Th.U. per square foot per degree difference in temperature of air and temperature of water

$$= 1{\cdot}6(180 - 55) = 200 \text{ B.Th.U. per hour.}$$

$$\text{Total radiator surface} = \frac{230400}{200} = 1152 \text{ sq. ft.}$$

It should be remembered that the ratio of the grate area to the heating surface has some bearing upon the accuracy of the estimated results. In small boilers the grate area is comparatively large; therefore calculations based upon the preceding may be misleading, as a larger proportion of heat will be lost than in boilers having a greater ratio of heating surface to grate area. In the latter case the indirect surfaces absorb a quantity of heat from the gases, etc. In the former case the surface will have a higher heat-transmission rate per unit area, but a larger quantity of heat will pass away with the products of combustion.

FIG. 225.—Lumby's Saddle Boiler *in situ.*

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For a small boiler (whose heating surface is practically all direct) with a grate area of less than 3 sq. ft. the rate of transmission of heat per square foot of surface may be taken as between 3500 to 6000 B.Th.U. per hour. Four thousand five hundred British Thermal Units is a conservative estimate, and will prove satisfactory.

The ratio of grate area to boiler surface in different types of boiler is as follows:—

Conical and dome-top boilers, grate area . . .	1 sq. ft.	to	8-10 sq. ft.	
Cross tube boilers, grate area .	1 „	„	12-16 „	
Sectional „ „ .	1 „	„	12-20 „	

Although catalogue ratings of boilers rarely include calculations based upon fuel consumption and grate area, manufacturers are always willing to give the fullest information respecting their boilers.

Brick-enclosed Boilers are of various shapes. They are made of cast-iron or of wrought-iron, and are so designed and fixed that the major portion of their entire surfaces comes in contact with either the fire or the heated products of combustion.

They do not last as long as the independent boilers, owing chiefly to corrosion of the parts that are in contact with brickwork.

Fig. 225 shows a part section and elevation of a "saddle" boiler *in situ*. The heated gases from the furnace are caused to pass around the outer surface of the boiler before passing into the chimney.

This boiler is suitable for use up to 500 sq. ft. of radiation surface. It is usually made of wrought-iron, with either welded or riveted joints.

Fig. 226 shows a section through a modified form of saddle boiler. In this example the end of the boiler has a waterway: a cross-head waterway is also provided, which the heated gases strike as they pass to the exterior of the boiler.

Independent Boilers are of two principal types: those which have a definite size, and those of the "sectional" type, which may be enlarged by adding sections to them.

The former are made of either cast or wrought iron, and are

either cylindrical or rectangular in shape. Sectional boilers are invariably of cast-iron.

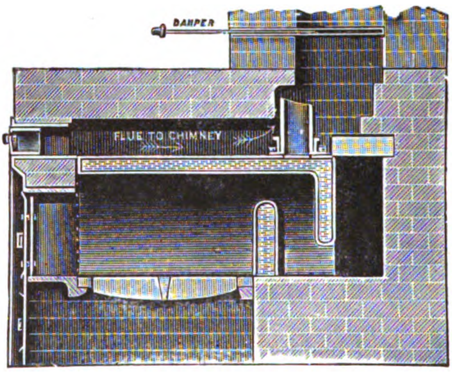

Fig. 226.—Lumby's "Jubilee" Boiler.

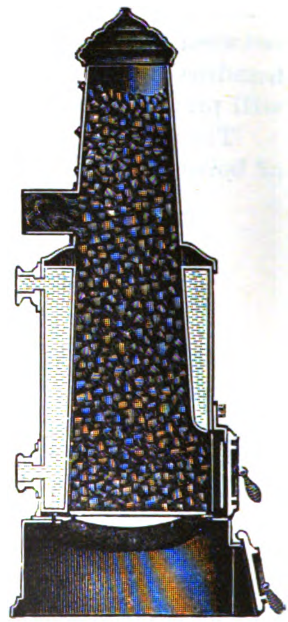

Fig. 227.—Lumby's Independent Cylindrical Boiler.

Fig. 227 shows a section through a simple pattern of independent boiler suitable for small systems up to 200 sq. ft. of radiation surface. The feeding tube allows the boiler to be charged with fuel sufficient for twelve hours.

Fig. 228 shows a dome-top boiler which is practically an extension of the one shown in Fig. 227. The horizontal surface at the top greatly increases the efficiency of the boiler. The waterway between the fire door and the feeder is dispensed with, as it was found that when used with water containing a large quantity of suspended matter, the deposit in the waterway immediately above the fire box, if not frequently removed, caused permanent injury to the boiler. It is formed of wrought-iron with welded joints. The interior surface may be either galvanised or Bower-Barffed to prevent corrosion. The former treatment is of no use when used in contact with pure or acid water, and the efficient application of the latter process to the interior of a boiler is a doubtful quantity.

To increase the heating surface without materially increasing the size of a dome-top boiler, horizontal waterways, in the form of circular, oval, or rectangular conduits, are placed across the fire box.

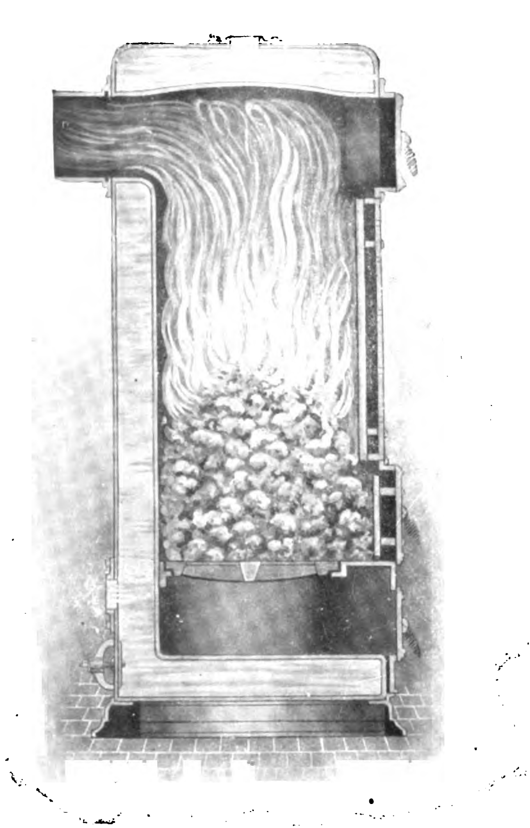

FIG. 228.—Hartley & Sugden's "Saville" Boiler.

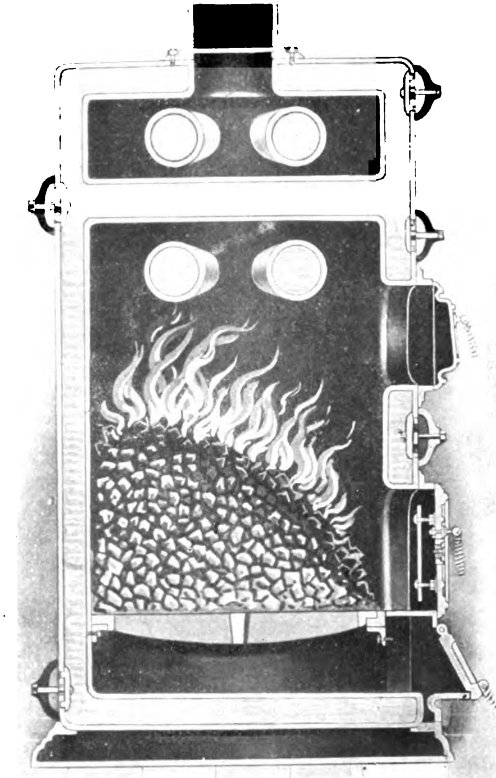

FIG. 229.—Lumby's "Goliath" Boiler.

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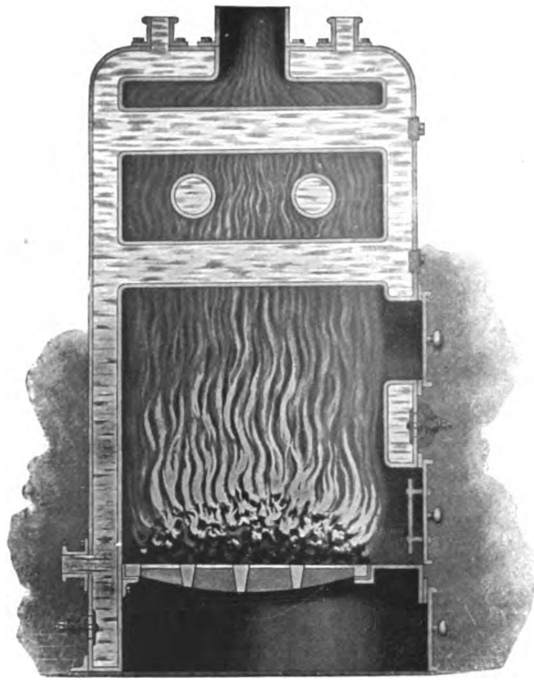

Fig. 230.—Hartley & Sugden's Dome-top Boiler with Water Tubes.

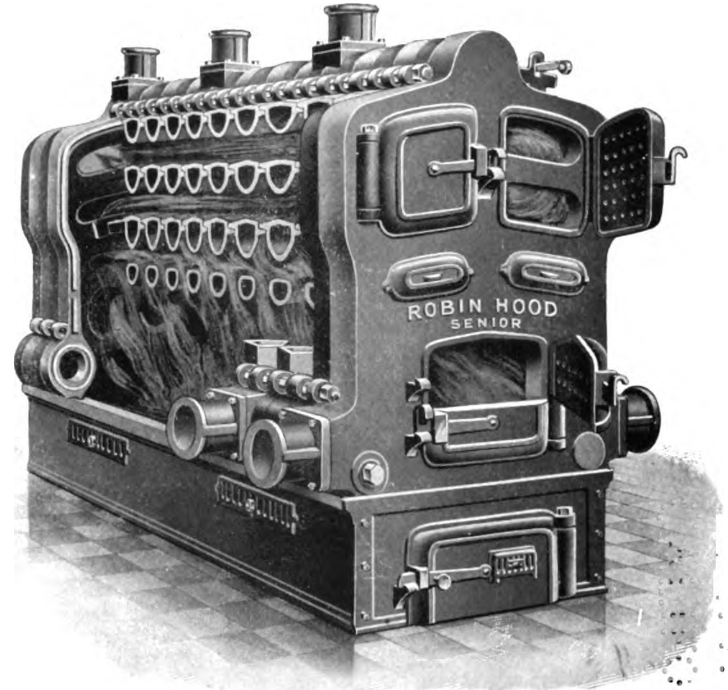

Fig. 231.—Beeston "Robin Hood" Sectional Boiler.

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Fig. 229 shows a boiler having six horizontal tubes in the upper part. In Fig. 230 four circular tubes are provided in pairs which cross at right angles.

In cross conduits of all types it is advisable to incline the tubes so that the water will circulate rapidly through them.

These boilers have a comparatively high efficiency, and are suitable for schemes involving from 400 to 5000 sq. ft. of radiating surface.

Mud lids or plugs are provided at one end of each tube, and also at the base of the boiler.

The fire boxes are large enough to hold ten hours' supply of fuel.

They are compact, and are suitable for boiler apartments having a limited floor space but possessing a vertical height of 8 or 10 ft.

Sectional Boilers have been largely used during the past ten years. They are of the "independent" type, and are built up in sections. Each section possesses a definite amount of heating surface. The ratio of the grate area to heating surface is constant for any number of sections in one boiler, as each section provides a fixed area of grate surface.

The sections are of cast-iron, with one or more waterways at the top and bottom.

They are connected together by double taper nipples inserted between the sections.

A special cement is used in the process, and all the sections are tightened simultaneously by long wrought-iron bolts which pass through the nipples, or they are bolted together by means of short bolts passed through lugs cast on each section.

By inserting blank nipples the boiler is divided into two separate compartments, each of which may be used independently or in combination with the other.

Fig. 231 shows a part section through the "Robin Hood" sectional boiler. The sections are secured by short bolts, left- and right-hand threaded. One or more flow-pipe connections are provided at the top of the boiler. The returns are connected to the bottom waterway on each side of the boiler.

Soot doors are provided for cleaning the cross tubes.

This boiler can be obtained in sizes to maintain systems of from 300 to 5000 sq. ft. of radiation surface.

The fire box has a large capacity, and will hold sufficient fuel for a night's requirements, if the damper be adjusted to reduce the draught.

Fig. 232 shows the "White Rose" sectional boiler. It is compact and efficient. A "magazine feeder" is provided in conjunction with the large fire box to receive a charge of fuel which will last twelve hours.

Fire Bars should be of chilled cast steel, interchangeable, and fixed in short lengths.

In the larger types of sectional boilers, *rocking bars* are occasionally used. The bars are agitated by a lever fixed on one side of the boiler. The ashes are thereby deposited in the ash pit without opening the fire box door.

An Automatic Damper Regulator controls the draught by altering the position of the baffle valve or damper in the smoke nozzle of the boiler. It generally consists of a flexible metal box containing a highly volatile fluid which is sensitive to small changes of temperature. When a maximum temperature is obtained, the box is expanded and levers connected with the damper are operated thereby.

When attended to periodically they may save fuel by regulating the air supply to the fire, according to the varying requirements of the system.

Independent boilers should be coated with a poor conductor of heat to prevent loss by radiation from their external surfaces.

It is essential for success that the boiler shall have a capacity of from 25 per cent. to 50 per cent. above the normal requirements of the scheme. Unsatisfactory results are oftener due to insufficient boiler capacity than to any other cause.

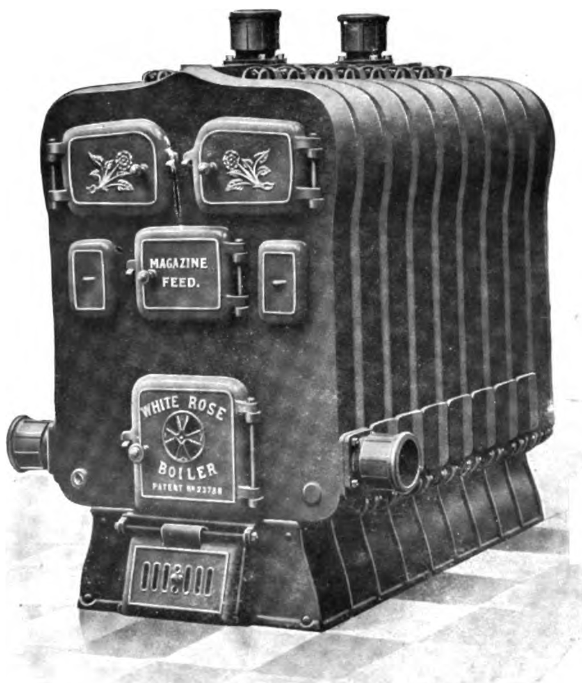

Fig. 232.—Hartley & Sugden's "White Rose" Sectional Boiler.

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CHAPTER XVI

HIGH-PRESSURE HOT-WATER SYSTEM—PIPES AND FITTINGS FOR SAME—ADVANTAGES AND DISADVANTAGES

Heating by high-pressure hot water is not often adopted in the case of private houses, but is occasionally applied to schools, warehouses, etc.

It consists of a hermetically sealed system of pipes attached to one or more coils of pipe which form a boiler.

The pipes used for boiler and radiating purposes are $\frac{7}{8}$ in. internal diameter, and are exceptionally strong. These are coupled by means of left- and right-hand threads of a finer

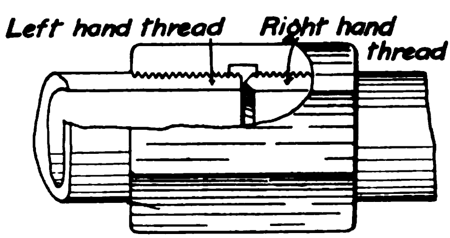

Fig. 233.—High-pressure Wrought-iron Pipe Joint.

character than are used for gas pipes. One pipe end is chisel-shaped, and is forced into the flat surface of the opposing pipe end by tightening the coupling shown in Fig. 233. No jointing material is necessary.

An Expansion Tube is provided at the highest point of each system to accommodate the increase in volume of water due to heating.

The capacity of this tube should be equal to one-fifth the total water-capacity of the apparatus.

The Temperature obtainable in the circulating water

varies from 250° to 800° F. Generally a temperature of 350° to 400° F. is considered sufficient for the warming of buildings.

Fig. 234 shows a small system based on the high-pressure principle. The boiler B is formed of ⅞ in. hydraulic strength wrought-iron pipe coiled inside a fire box. The circulating pipes are of the same diameter and strength. The flow pipe generally rises to the highest point by the shortest route, where it joins an expansion tube, E. One or more returns are branched from the flow pipe, and, passing through the various rooms, eventually join the boiler at A.

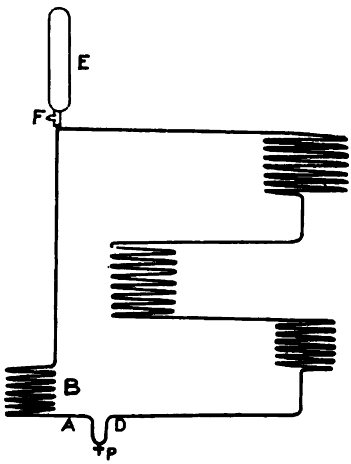

FIG. 234.—High-pressure Hot-water System.

A dip pipe, D, is formed on the return to prevent reverse circulation. At the bottom of the dip a tee, P, is provided, to which a pump can be attached for filling the apparatus. The tee has a reflux valve which closes when the pump is removed. The pipes are charged with water to the level of the overflow F., the air being expelled meanwhile. The overflow is plugged and the apparatus is then ready for use.

A small quantity of water is added periodically to compensate for the loss through the pores of the iron pipe.

The high temperatures obtainable in this apparatus are due to the pressure to which the water is subjected by compression of the air in the expansion tube E. The higher the temperature of the water the greater will be the pressure, owing to the accumulation of the surplus hot water in the expansion tube.

Pressures of 1000 lbs. per square inch have been experienced with these systems.

Although the flow pipe is usually taken vertically to the highest point, the return pipes can be dipped without fear of air locks developing.

Where concentration of radiating surface is desired, the pipes are coiled or "returned" a requisite number of times.

If more than one circuit be used, it is advisable to have special stopcock tees to regulate the flow of water through each circuit.

In the case of large installations, several coils of pipe are required to produce a boiler of requisite capacity. The flow pipe from each coil in the fire box is the lead for a separate circuit, the return pipe of which is connected to the bottom of another boiler coil.

In this manner an efficient circulation is obtained in each circuit without resorting to branch pipes. At the same time, only one expansion tube is necessary, as the circuits intercommunicate with each other. The high temperatures experienced in this system render it necessary to avoid contact of the pipes with combustible substances such as wood. Where this cannot be avoided, a sheet of asbestos should be placed between the pipes and the wood.

The advantages of the high-pressure hot-water system are:—

1*st*. Smaller bore pipes are used, which also may be fixed with a minimum of expense.

2*nd*. Less radiating surface is required, as compared with other systems; also, the rate of heat transmission is higher per unit area per degree difference in temperatures of the air and the water, compared with the rate of transmission obtaining in the low-pressure system.

3*rd*. Temperatures up to 800° F. can be obtained without difficulty, as required in the case of drying or japanning rooms.

4*th*. The temperature of the water can be raised to the maximum within one hour.

The disadvantages are:—

1*st*. The risk of explosion in case of defects developing.

2*nd*. Fluctuations of temperature of the water in the pipes owing to irregular stoking.

3*rd*. The air in the rooms has a burnt smell due to charring of the organic dust by contact with the heated pipes.

4*th*. Exposed pipes are liable to be touched accidentally by the bare flesh of persons using the building. This is especially risky in the case of children. Severe burns have been occasioned thereby.

The proportion of boiler surface to radiating surface varies with the size of the installation and the temperature at which it is desired to maintain the air.

For small domestic buildings 1 sq. ft. of boiler surface is considered to be sufficient for 10 sq. ft. of radiating surface, but for larger schemes and those requiring higher temperatures, the ratio varies between 1 : 9 and 1 : 7.

To prevent freezing when the apparatus is not in use during winter, the pipes may be charged with an anti-freezing solution.

CHAPTER XVII

STEAM HEATING—VARIOUS MODES—RADIATOR AND PIPE ARRANGEMENTS—BOILERS, ETC.

THE relationship between hot-water heating systems, and systems of steam heating is confined to the provision of the boiler and the system of pipes or conduits that are necessary in each case. The heat conveying medium used in the former system has entirely different characteristics to that employed in the latter system.

The "latent heat" of vaporisation of water is 966, which means that 966 B.Th.U. are required to convert 1 lb. of water at 212° F. into steam at the same temperature. Conversely, if 1 lb. of steam at 212° F. be condensed to water at the same temperature, 966 B.Th.U. will be released.

This feature makes steam a valuable heat conveying medium.

The small quantity of water necessary to produce a large volume of steam is a factor which has to be taken into account when designing a steam-heating apparatus.

One cubic inch of water will produce 1640 cub. ins. of steam at normal atmospheric pressure. Owing to the elasticity of steam, it is reduced in volume by an increase of pressure.

It will thus be seen that a few pounds of steam will be sufficient to entirely fill the pipes and radiators of a large heating system.

The rapid condensation which occurs when steam is in contact with cooled surfaces makes it necessary to maintain an adequate supply of steam to all parts of the apparatus.

Assuming that the radiating surface in a steam-heating system of 2000 sq. ft. emits 300 B.Th.U. per square foot per hour. The total requirements per hour in B.Th.U. = 300 ×

2000 = 600,000. One pound of steam at atmospheric pressure occupies 47,500 cub. ins. approximately, and when condensed, evolves 966 B.Th.U. Therefore $\frac{600,000}{966} = 621$ lbs. (or 29,524,500 cub. ins.) of steam required per hour.

The large volume of steam required per hour has to pass through comparatively small conduits. The sizes of the latter are of first importance. If they are too small, partial vacuums are formed, followed by hammering noises due to the displacement of the water of condensation by a sudden inrush of steam. Pipes of large diameter are necessary to ensure success.

The modes of heating by steam are:—

High-pressure system (above 10 lbs. per square inch).

Low-pressure system (up to 10 lbs. per square inch, but usually from 2 to 5 lbs. per square inch).

Atmospheric pressure system.

Exhaust steam system.

The high-pressure system is only adopted where steam at high pressure is used for other purposes, as in mills and factories. The condense is generally dealt with by steam traps, and is conveyed to the "hot well," or discharged into the drainage system.

By the use of an injector the condense can be returned directly to the boiler, and steam traps dispensed with.

Where either low-pressure or atmospheric heating is adopted for residences, public buildings, or works, it is necessary to provide a special boiler for generating the steam, unless one is already installed to produce steam for other purposes.

With the use of special boilers, the "gravity return" principle is always adopted. The pipes are arranged so that the water of condensation is returned to the boiler. Constant attention to the water-level in the boiler is unnecessary. A small quantity of water is admitted to the boiler each week when the apparatus is not in use.

The methods of piping are:—

One-pipe system.
Two-pipe system.
Drop-pipe system.

In **the one-pipe system**, the steam and condense pass in the

same directions through the main pipe, but in all branch pipes or risers connected with this pipe for supplying radiators on one or more floors, the steam and condense pass in opposite directions through the same pipe.

Fig. 235 shows a simple arrangement of pipes on the one-pipe system for low pressure. The main steam pipe rises to a point A, whence it has a gradual declination to the point B. The condense formed between the points A and B, passes in the same direction as the steam, and eventually enters the boiler through the vertical return C.

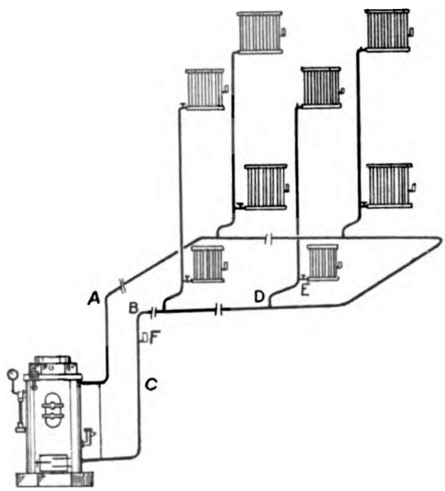

FIG. 235.—One-pipe System of Low-pressure Steam Heating.

It will be seen that the vertical pipes or "risers" which supply steam to the radiators also convey condense to the steam main.

This is the simplest arrangement of pipes, and is suitable for small systems.

The offset D E is formed to allow freedom of movement of the riser without depressing the main, A B, or tilting the radiators. The latter practice is often responsible for leaking joints and breakage of radiator connections.

In all long lengths of steam mains provision for expansion and contraction must be made. This is usually accomplished by forming double bends or breaks, as shown at D E. This also

applies to horizontal mains, the pipes being projected for a short distance and then returned to the original alignment.

It is usual to provide a stop valve on each radiator. This can only be used when the radiator is put in or out of use. The steam supply to the radiators cannot be regulated to suit the varying requirements of the outer air; it must be full on or shut off entirely. If a substantial variation of the temperature of the room be desired, the radiating surface in all the important positions should be assembled in two groups or radiators, so that one of each pair can be shut off if required.

Each radiator must have an automatic air valve which will permit the air to escape when the apparatus is started; also, in long lengths of steam pipe, air relief valves are necessary.

If the air is not entirely dislodged from the pipes and radiators, a portion of it may accumulate in the radiators and prevent contact occurring between the steam and the cooling surface, thereby materially reducing the radiating area.

It is usual to fix the air valve near the centre of the radiator. The specific gravity of steam is considerably less than that of air, but this factor is somewhat discounted by the velocity at which the steam travels through the pipes. A portion of the air is pushed forward in front of the steam. Mixing of the two also occurs.

In some instances air valves are fixed at low points on the return pipes, as at F, and occasionally on the high points of the flow pipes.

The automatic air valve shown in Fig. 223 is suitable for the purpose. The air imprisoned between the inner and outer cylinder expands when heated by steam entering the valve, and forces the water into the inner chamber. The float valve is raised by the influx of water and prevents the escape of steam.

Extreme care is necessary in designing the pipe arrangements, as the water and steam travel in opposite directions through the same pipe in a large portion of the system.

Pipes of large diameter are necessary to prevent annoying conflicts between the two fluids.

The Two-pipe System is favoured by some engineers, as it provides for the quick removal of condense water; also, the steam and water flow in the same direction throughout the

apparatus, except in the flow "risers," where the water travels in the opposite direction to the steam. Flow and return "risers" are attached to each radiator, a valve being provided on each pipe where it joins the radiator.

When it is necessary to put a radiator out of action, both valves must be closed. If one valve be left open, steam will enter the radiator and probably cause "water-hammer," as the pipes in this system are generally smaller than those in the one-pipe system.

Fig. 236 shows a two-pipe low-pressure steam apparatus. The steam main rises to the point A, and then gradually

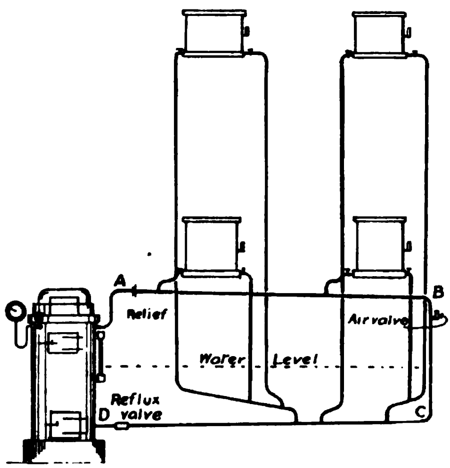

FIG. 236.—Two-pipe System of Low-pressure Steam Heating.

descends to B, where an air-relief valve is provided. Between these two points the "risers" to the radiators are connected.

To ensure a successful service of steam to the radiator and to prevent water-hammer, the condense return from each radiator is connected to the main condense pipe at a point below the water-level in the boiler. The main condense pipe descends vertically from B to C; from C it has a gradual fall to its connection with the boiler at D.

The length C D is below the water-line, and is known as a "wet" or "submerged" return, as it is constantly full of water. The return risers are connected to this pipe in such a manner

that their lower ends are entirely submerged, as illustrated in Fig. 236.

Pipes of small diameter connect the flow risers to the submerged return, and convey the condense from the former pipes to the latter pipes, thus preventing it from entering the steam main.

This arrangement of the condense return pipes ensures silent working of the apparatus by entirely eliminating any possibility of a by-pass occurring through which steam from one radiator could come in conflict with the water of condensation in the return pipe connected to another radiator.

A reflux valve is generally fixed on the "wet" return to prevent the water from backing up the pipe and flooding the lower radiators, when the difference between the pressures in the flow and return pipes is abnormal.

In some instances the return risers are connected together before joining the condense return pipe to reduce the cost of the scheme, but there is some risk of the steam entering the radiators through both pipes, thus causing water-hammer by conflict with the condense.

The Overhead or Drop-pipe System consists of an arrangement of pipes by which steam is supplied to the radiators on the one-pipe principle.

One or more steam mains arise vertically by the shortest route to the highest floor. Vertical branch pipes are connected to these mains to supply radiators on the lower floors. The radiators on the top floor are connected to the horizontal steam mains.

Fig. 237 shows a small scheme on the overhead principle for low-pressure steam.

The flow pipes should be covered with a non-conductor of heat to reduce the loss of heat, and also the quantity of condense to be dealt with by the drip or relief pipes D D. The condense and steam pass in opposite directions through the flow pipes, but throughout the remainder of the system they flow in the same direction.

Each radiator is connected by a single pipe to the steam main, and is controlled by a valve.

An air relief valve is fixed about the centre of each radiator, also at the termination of each condense return.

Where more than one return riser is coupled to the main condense return, the submerged principle of connecting the pipes must be adopted, to ensure noiseless working.

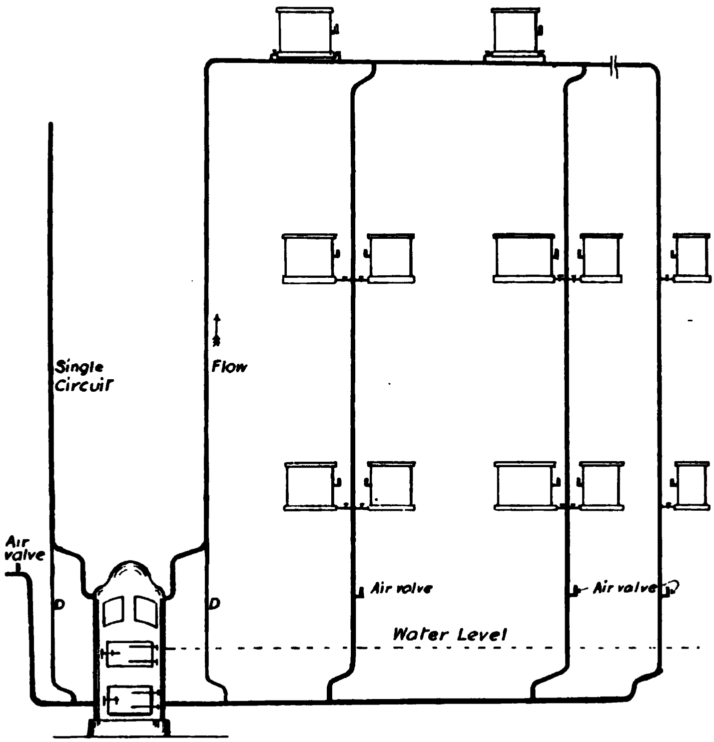

FIG. 237.—Overhead System of Low-pressure Steam Heating.

The Atmospheric System of Steam Heating is similar in certain parts to the two-pipe system using low-pressure steam, but the condense is returned to an enclosed tank, whence it passes into the boiler.

This system permits of some degree of regulation of the steam supply to the radiators without producing water-hammer.

Fig. 238 shows a simple example of this system.

A pressure of from 1 to 3 lbs. of steam is maintained in the boiler.

The collecting tank is fixed at a height above the boiler

which will overcome the head of steam and allow the water to enter the boiler.

A relief pipe, R, is provided to relieve accumulations of pressure in the boiler. The condense enters the boiler through the pipe in the bottom of the tank.

The tank is open to the air through the pipe A, as also are all the principal condense returns, as shown at B B.

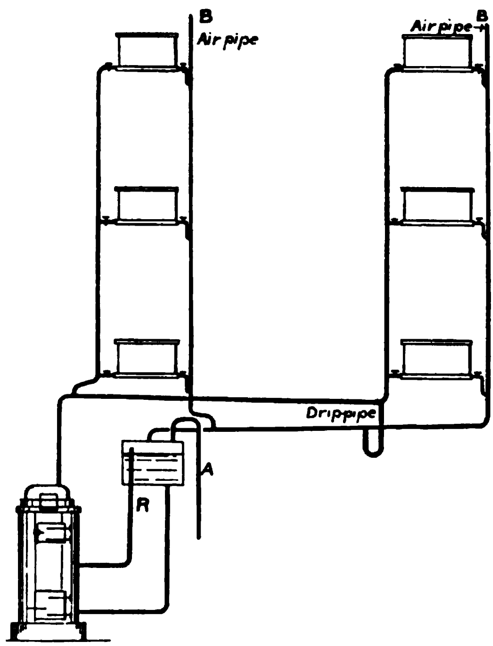

FIG. 238.—Atmospheric System of Steam Heating.

The Exhaust Steam System can be adopted on premises where steam-power is used.

When the expansive force of high-pressure steam has been absorbed by steam-engines, the latent heat still remains and is available for warming purposes by passing it through pipes or radiators.

It is essential that the condense pipes be connected to either an exhauster constructed on the ejector principle or to a vacuum pump.

If a sufficient quantity of exhaust steam be available,

this system is the most economical of any as regards maintenance.

The radiators used in steam-heating installations are similar in principle to those used for low-pressure hot water heating, but in some cases the connections between the sections are stronger. Some makers provide one kind of radiator suitable for steam or hot-water systems.

The pipes may be of either wrought or cast iron. The latter is used for large pipes, and the former for pipes less than 3 ins. diameter.

The Sizes of Pipes are governed by the type of system, local requirements, and cost. The latter factor is often allowed to influence the sizes of pipes to the detriment of a system.

It is of the greatest importance that large capacity pipes be used, otherwise hammering noises and an insufficient supply of steam to fully maintain all parts of the apparatus will be experienced.

For long mains, pipes of larger diameter will be necessary than those required for short mains; also, in the one-pipe, atmospheric, and exhaust systems larger pipes will be necessary than in the two-pipe system.

Formulæ are available for determining the diameters of steam mains, but the varying conditions which obtain make it necessary to modify the sizes of pipes as determined.

A rule which is applicable to the majority of one-pipe systems, is to allow ·7854 sq. in. (*i.e.* the sectional area of a pipe 1 in. diameter) of main area for each 100 sq. ft. of heating surface.

Thus:—

A 1-in.	pipe	will supply	100 sq. ft. of radiating surface.			
A 1¼-	„	„	100 to 150	sq. ft.	of radiating	surface.
A 1½-	„	„	150 „ 220	„	„	„
A 2-	„	„	220 „ 400	„	„	„

The minimum size of the main steam flow pipe should be 1½ ins. diameter.

It is usual to have the return pipes one or two sizes less than the flow pipes, as there is great disparity between the volumes of the fluids passing through each pipe.

In the two-pipe system a larger quantity of radiating

surface can be supplied by the same size of pipe than in the one-pipe system.

Thus a steam main in this system will carry 120 to 140 sq. ft. of radiating surface for each ·7854 sq. in. of its cross-sectional area.

Traps or dips must be avoided, unless they are provided with drips or relief pipes.

The water which accumulates in these positions will give rise to unpleasant noises unless it is automatically drained away.

Steam Boilers.—There is the same ambiguity obtaining in the rating of these as in the case of low-pressure hot-water boilers.

They are rated on the "horse-power" basis: the radiating surface that they can carry, the total number of British Thermal Units that can be transmitted per hour; also, the area of radiating surface that can be carried per square foot of grate area.

If the latter be a conservative estimate, and the boiler surface and grate area are properly proportioned, it is the safest basis to work upon.

Steam at 5 lbs. pressure per square inch will have a temperature of 227° F., and 1 sq. ft. of radiating surface will transmit 300 B.Th.U. per hour (approximately), with the air at 60° F. and steam at 5 lbs. pressure.

Assuming that 9 lbs. of coal* or coke* are burnt on each square foot of grate per hour, and that 50 per cent. of the calorific value of the fuel is absorbed by the boiler, the total British Thermal Units available are—

$$\frac{9 \times 10000 \times 50}{100} = 45000,$$

and the radiating surface which 1 sq. ft. of grate area will carry

$$= \frac{45000}{300} = 150 \text{ sq. ft.}$$

This is a conservative estimate, and in many cases will be exceeded, but much depends upon the ratio of direct to indirect boiler-heating surface, the kind of fuel used, and the manner of firing.

* See p. 229.

Each boiler should have a safety valve and a water gauge.

The regulating of the rate of steam-raising so that a fairly constant head of steam is maintained, is difficult to accomplish by the irregular attention which is generally given to boilers of small systems. To obviate this difficulty an automatic regulating damper is used. The rate of fuel consumption is thereby controlled to meet the varying requirements of the system.

FIG. 239.—Ideal "Premier" Steam Boiler.

Fig. 239 shows a view of a steam boiler suitable for small installations up to 800 sq. ft. of radiating surface. An automatic regulating damper is attached to the steam flow pipe and connected with the air door, which it opens or closes according to the head of steam in the boiler.

Fig. 240 shows the section and view of a mild steel riveted boiler of the vertical type suitable for pressures up to 60 lbs. per square inch. It is so constructed that a large heating surface is exposed to the direct action of the fire. It is obtainable in sizes capable of maintaining from 200 to 2000 sq. ft. of radiating surface on the low-pressure system.

Mud lids are provided for inspection and access for cleaning the cross tubes and other parts of the boiler.

For larger installations a boiler of the multitubular type similar to that shown in Fig. 241 may be used. The heated gases pass through one battery of tubes and return through a second battery, thus travelling twice the length of the boiler.

An automatic damper regulator is shown attached to the smoke flue.

Boilers of this type for low-pressure steam heating can be obtained in sizes sufficient to maintain 4500 sq. ft. of radiating surface.

The chief disadvantages of steam heating are: (1) Fluctuations of temperature due to improper firing; (2) the extra cost of fuel, which is estimated at from 10 to 20 per cent. by different authorities; (3) the noises that are liable to occur

even in well-designed systems; (4) radiating surfaces the temperature of which exceed 212° F., thereby rendering the air unpleasant. Complaints are sometimes made of the enervating effect of the air upon the occupants of the room.

Its chief advantages are: higher radiating values per unit area are obtained; the temperature of the apparatus can be raised to its maximum in a much shorter time than is necessary in low-pressure hot-water systems.

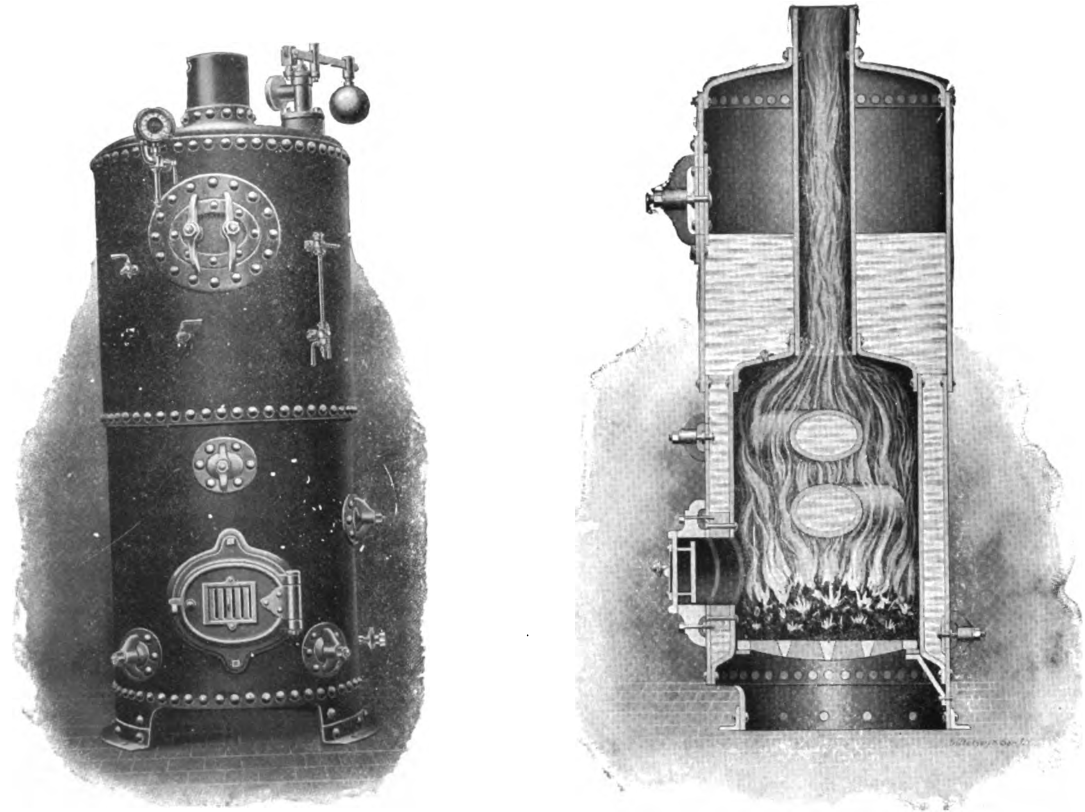

FIG. 240.—Hartley & Sugden's Vertical Steam Boiler.

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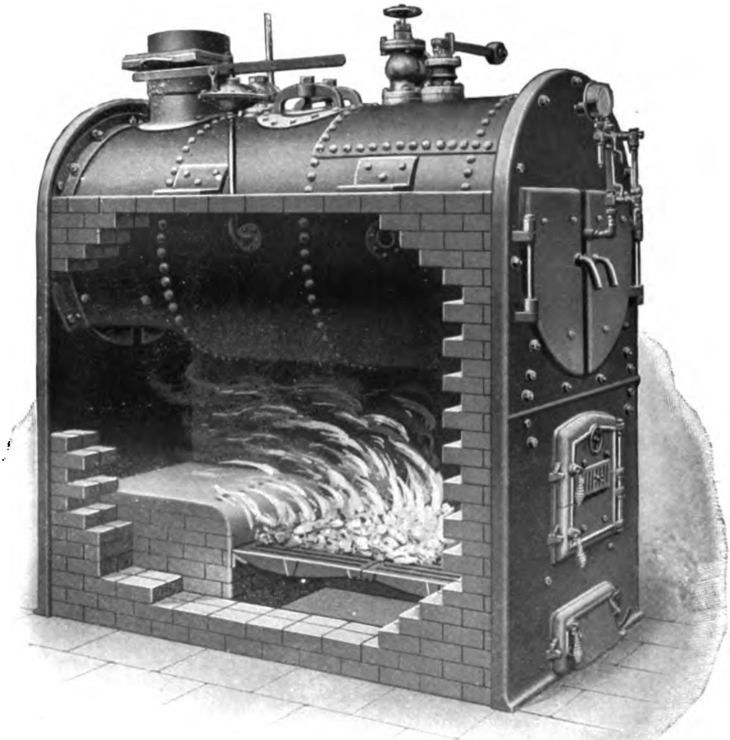

FIG. 241.—Lumby's "Nestor" Multitubular Steam Boiler.

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CHAPTER XVIII

VENTILATION OF BUILDINGS, METHODS OF ESTIMATING POLLUTION OF AIR—QUANTITIES OF AIR REQUIRED—NATURAL VENTILATION AND MECHANICAL VENTILATION

The term Ventilation means the changing of the air contained in a building or any type of enclosed space.

In dwellings and in all kinds of public buildings inhabited or used by human beings, the air is polluted by the exhalations from the lungs and skin of the occupants and the combustion of illuminants.

Normally pure air is composed of:—

	Per cent.
Oxygen	20·96
Nitrogen	79·00
Carbon dioxide . . .	·04
	100·00

(Also a variable quantity of water-vapour.)

Air which is expired from the lungs is composed of (approx.):—

	Per cent.
Oxygen	16·96
Nitrogen	79·00
Carbon dioxide . . .	4·04
	100·00

It is saturated with moisture, and contains particles of organic matter.

A comparison of the two analyses indicates that whereas the quantity of nitrogen remains constant, oxygen is abstracted from, and CO_2 added to, the air during respiration. Also, a

quantity of organic matter and water-vapour has passed along with the air from the lungs.

An average adult when at rest breathes from twenty-five to thirty-five times per minute. The quantity of air taken into the lungs at each normal inspiration = from 20 to 30 cub. ins.

From the table of the composition of inspired and expired air, it will be seen that 4 per cent. of CO_2 is added to the latter. The quantity of CO_2 which an adult will give off per hour when at rest equals:—

$$\text{Volume of air entering lungs per hour} = 20 \times 25 \times 60$$
$$= 30000 \text{ cub. ins.}$$

4 per cent. of this quantity = amount of CO_2 added per hour.

$\therefore$ amount of CO_2 added to the air per hour by each adult

$$= \frac{30000}{1} \times \frac{4}{100} = 1200 \text{ cub. ins.}$$
$$= \cdot 6 \text{ cub. ft. (approx.)}$$

If a person is engaged in laborious physical work, greater quantities of CO_2, organic matter, and water-vapour will be given off.

It is generally accepted as the basis of calculations that each adult (*i.e.* person over sixteen years) gives off ·6 cub. ft. of CO_2 per hour when at rest.

Impurities in the Air of inhabited buildings are deleterious to the health of the occupants. In addition to the respiratory products, there are other polluting agents. The waste gases from the combustion of oil and coal-gas, when used as illuminants; dust, either blown in, or carried in on the boots; smoke; CO_2; CO; and sulphurous compounds which escape from closed stoves, are common in some instances.

The chief impurities, however, are those given off from the lungs.

To maintain an inhabited building in a healthy state, it is essential that *the air be regularly changed a requisite number of times per hour*, in order to dilute and remove the impurities imparted to it by the occupants.

This is particularly the case where people congregate in large numbers in comparatively small buildings.

Insufficient Ventilation, particularly in the case of

dwellings, workshops, and factories, is one of the causes of the spread of disease. This is especially so with tubercular diseases such as phthisis and pulmonary consumption. One infected person occupying, along with other persons, a badly-ventilated room is liable to infect the whole of the occupants.

Although the quantity of CO_2 which each person adds to the air per hour is taken as the standard when determining the amount of air to be supplied under given conditions, *the organic matter given off from the lungs is the most dangerous factor.* It consists of living and dead organic particles, which, when inhaled in large quantities, gives rise to headaches, sickness, and faintness.

The quantity given off per hour bears a fairly definite ratio to the amount of CO_2 emitted in the same time; therefore the latter is used as the standard, as it can be determined quantitatively without difficulty.

A person passing directly from the fresh air into a badly-ventilated room will detect an unpleasant nauseating odour in the air of the room due to an excess of organic matter.

It must not be assumed that an excess of CO_2 in respiratory air is not deleterious; if present to the extent of 3·5 per cent., life cannot be supported; but quantities of 2 per cent. or less, although they cause sickness, are rarely fatal.

Standards of purity which define the amount of respiratory CO_2 that may be added to the air in buildings have been determined as the result of investigation and experience.

Most experts are agreed that the CO_2 should not be increased by respiratory addition beyond ·6 part per 1000 parts of air, if healthy conditions are to be observed.

Normally pure air contains on an average ·4 part of CO_2 in each 1000 parts of air; therefore the difference between the "standard quantity" of CO_2 and that already in the air $= \cdot 6 - \cdot 4 = \cdot 2$ part per 1000 parts of air.

Each adult produces ·6 cub. ft. of CO_2 per hour.

The amount of CO_2 which may be added to each 1000 cub. ft. of air = ·2 cub. ft.

Therefore each individual must have $\frac{\cdot 6}{\cdot 2} \times 1000 = 3000$ cub. ft. of air supplied to him per hour to dilute the impurities so as to comply with the standard.

Lower standards, such as ·70, ·80, ·85, and ·90 part of CO_2 per 1000 parts of air, are adopted in many instances. With these, smaller quantities of air are required per head per hour, but the conditions are not as healthy as obtains with the adoption of the higher standard.

With the ·70 standard, ·7 − ·4 = ·3, $\frac{\cdot 6}{\cdot 3} \times \frac{1000}{1} = 2000$ cub. ft. of air are required per head per hour;

and with the ·80 standard, ·8 − ·4 = ·4, $\frac{\cdot 6}{\cdot 4} \times \frac{1000}{1} = 1500$ cub. ft. of air per head per hour.

The size of a room does not influence the quantity of air required by each individual, but it governs the number of changes of air required per hour.

Thus, if the total capacity of a room is such that each individual has 1000 cub. ft. of air space, the number of changes of the air per hour to comply with the ·6 standard is $\frac{3000}{1000} = 3$.

Where a smaller quantity of air space per head is available, the rate of change of the air will be increased.

If the air space per head = 600 cub. ft., then $\frac{3000}{600}$ = five changes per hour.

The height of a room is considered apart from the other dimensions. In natural systems of ventilation the air space in the upper portion of a room exceeding 12 ft. in height is not usually included in the ventilation scheme. It has been demonstrated that the respiratory products tend to accumulate in the vicinity of the persons occupying the room, and do not intimately mingle with the upper stratum of air.

The chief points to which attention must be given in all ventilation schemes are:—

1*st*. Provision for the supply of an adequate quantity of air.

2*nd*. Even distribution of the fresh air through all parts of the building.

3*rd*. Provision for the effective removal of vitiated air.

4*th*. The incoming air must be warmed, or so delivered that cold air currents will not impinge upon any of the occupants of the building.

5th. The inlets and outlets must be fixed as far apart as possible.

The ventilation of a building can be achieved by **the natural system,** or **the mechanical system.**

In the former case natural forces are relied upon for changing the air in the building. These forces are: (1) The wind; (2) diffusion of gases; (3) the force caused by the difference in density due to difference in temperature of the air inside and outside the building.

The force of the wind is a very variable quantity and cannot be relied upon, but it has to be taken into account when arranging the positions of the air inlets and outlets, otherwise a reversal of the air currents may occur, with unpleasant consequences.

The term "diffusion" is used to indicate the properties which all gases possess of mingling intimately with each other. CO_2, SO_2, and other gases denser than air diffuse into the air at a rate which varies inversely as the square root of their respective densities.

It has been estimated that the air in a room of from 2000 to 3000 cub. ft. capacity, is entirely changed by diffusion once in each hour. Although the action is constantly going on—vitiated air diffusing through the walls of the building into the outer air, and fresh air diffusing into the vitiated air in the building—it is ignored when estimating the air requirements for the proper ventilation of a building.

The chief factor in natural ventilation is the different densities of the air inside and outside a building.

During warm weather an adequate supply of air may be obtained by opening the windows and doors, but in cold weather this mode could not be adopted, as the outer air is then much colder than that inside an inhabited building.

By an arrangement of inlets or outlets the colder air, by reason of its greater density, displaces the vitiated warmer air and forces it through the outlets.

The velocity at which air is permitted to enter a room will be governed by its temperature.

Air at 45° F. entering a room in which the air is at 60° F., at a velocity of more than 2 ft. per second, will give rise to cold draughts which may be unpleasant to certain of the

occupants. If the temperature of the incoming air be raised to 70° F., it may attain a velocity of 6 ft. per second without causing any inconvenience.

It is stated that the velocity of the incoming air should not exceed 3 ft. per second, but the degree of discomfort caused by cold air currents is largely a matter of personal temperament and habit; one individual will experience no discomfort from a cold air current entering a room at a velocity of 5 ft. per second, whereas another may discover something unpleasant in a current of air at the same temperature but having a velocity of only 1 ft. per second.

Dwellings, hospitals, and buildings in which the cubic space per head averages between 600 and 1000 cub. ft. can generally be ventilated satisfactorily by natural means, but large buildings and those in which a small cubic space only is allowed per head are more satisfactorily ventilated by mechanical means.

Air inlets and outlets.—In all cases it is necessary to provide inlets for the admission of fresh air and exits for the escape of vitiated air. The relative positions of inlets and outlets should be such that air currents cannot pass directly from one to the other. This is best obtained by fixing the inlets as far as possible from the exits.

Sizes of inlets and outlets.—To ensure even distribution of fresh air throughout a room, the maximum cross-sectional area of any inlet in a natural system should not exceed 72 sq. ins. For small rooms it is advisable to have several inlets each of less area than 72 sq. ins., instead of one or two of that size.

Fewer outlets, but of larger size than the inlets, may be used.

It is advisable that the total area of the inlets be 25 per cent. greater than the area of the outlets, so that a slight pressure may be obtained in the room, and also to compensate for the greater friction obtaining in the smaller inlet tubes compared with that in the outlets.

From 20 to 30 sq. ins. of inlet should be allowed for each person. If the velocity of the air passing through the inlets be 3 ft. per second, this will provide $\frac{20}{144} \times \frac{30}{1} \times \frac{60}{1} \times \frac{60}{1}$

=1500 cub. ft. per hour, or, with the use of the higher figure, 2250 cub. ft. per hour.

The air entering through ill-fitting windows, doors, floors, and skirting boards is not taken into account, although in most cases the quantity is considerable.

In small dwellings the air inlets consist of windows made to open, and ill-fitting windows, doors, and floors. Special inlets are in some cases provided in the larger houses.

The principal exit for vitiated air is the open chimney. The heated gases from the fire are a valuable asset by reason of their aspirating effect upon the air in the room. In dwellings of moderate dimensions no other exit is necessary, but it should be seen that the chimney or fireplace is not blocked when the fire is not required.

For admitting fresh air to rooms ventilated on the natural principle, many special fittings are available, the chief of which are:—Hopper windows, Hinckes-Bird's window, Ellison's air brick, Tobin's tube, the Sherringham valve, and louvres of either glass or wood. Fresh air, particularly if it be cold, should enter a room at a height of not less than 5 ft. above the floor, and the current should take an upward direction, so that it will mingle with the warmer air before coming in contact with the occupants.

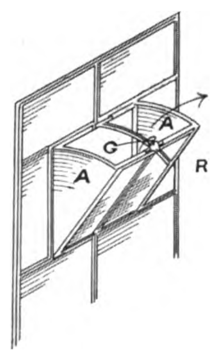

FIG. 242.—Hopper Ventilator.

Fig. 242 shows one form of **hopper window**. This type of air inlet is suitable for schools, churches, workshops, factories, and barracks. It is advisable to have sides of either glass or metal, so that the air will enter in an upward direction. A regulator, R, is provided for adjusting the size of the opening. The top of the hopper may be covered by a sheet of copper gauze. This diffuses the incoming air, but is useless as a screen. It also retards the flow, and thereby reduces the quantity of air delivered.

In the case of schools a large section of the upper portion of each window may be pivoted to allow of a large influx of air during warm weather and play-time of each day. It is advisable to have the whole of the window to open, where

possible, irrespective of the permanent provision for the admission of air, so that a rapid change of air can be effected if the rooms are unoccupied for only a few minutes.

Hinckes-Bird's window is a simple device which can be applied to any sash window frame. It consists of a deep bead in the place of the usual shallow one on the inner face of the sill. This allows the bottom sash to be raised about 2 ins. whilst its lower edge is below the top of the bead. The space between the meeting rails of the top and bottom sashes provides for the admission of fresh air.

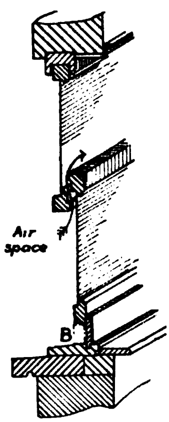

Fig. 243.—Hinckes-Bird's Open Window.

Fig. 243 shows this arrangement. In some instances it may be necessary to fix a block of wood, B, below the bottom sash to prevent it from being closed by people who object to fresh air.

It is one of the cheapest and most efficient of air inlets. The air current assumes the form of a wide thin band as it enters the room in an upward direction. It is not likely to cause unpleasant draughts.

It is suitable for dwellings and for either day rooms or dormitories in public institutions.

Air Bricks are used as air inlets, also as air outlets. Although they are suitable for the latter purpose, they cannot be regarded as serviceable inlets unless they possess a device for diverting the air current from a horizontal to a vertical direction.

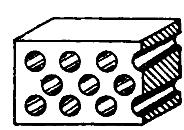
Fig. 244.—Ellison's Air Brick.

"Ellison's" air brick (Fig. 244) has perforations shaped like the frustum of a cone. The face having the enlarged ends is fixed inside the room. The incoming air is reduced in velocity as it passes through the expanding tubes.

Tobin's Tube is a very efficient type of air inlet. It consists of a circular or rectangular tube at one end of which a bend is formed. The horizontal portion projects through the wall, and is provided with a perforated zinc or cast-iron cover.

Fig. 245 shows a tube in position. The top is fixed from 5 to 6 ft. above floor level. The baffle valve A is used for regulating the air supply.

Canvas screens are placed in the tube outlets in some instances, as at B, in order to arrest dust. The pyramidal shape of the screen increases the area through which the air passes. The friction which they impose upon the air currents greatly reduces the volume delivered through the tubes; also, they require frequent cleaning, otherwise the flow of air will be entirely stopped.

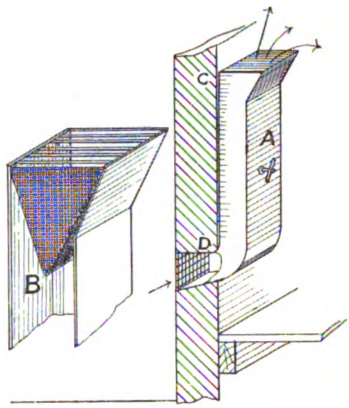

Fig. 245.—Tobin's Tube.

The length of the portion C D can be varied to suit requirements.

Sherringham's Valve (Fig. 246) is similar in principle to Tobin's tube. It consists of a cover hinged to a cast-iron frame or box, which is fixed in an aperture in the wall.

The size of the inlet can be reduced by moving the cover C towards the wall box. A copper screen may be attached to the

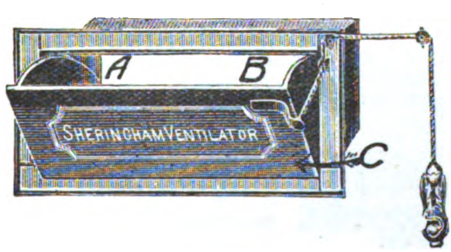

Fig. 246.—Sherringham's Valve.

top, A B, but it is of no service beyond that of diffusing the incoming air, whereas it materially restricts the flow.

Louvre Air Inlets consist of strips of glass, metal, or wood arranged in a framework of iron or wood. Generally, they are provided with devices for adjusting their position, and for regulating the quantity of air passing through them.

Fig. 247 shows a view and section of a louvre ventilator which can be used in the position of an inlet or of an outlet. The louvres may be fixed, or may have their ends pivoted and connected with a regulating bar or rod.

When used as inlets or outlets, the louvres have their lower edges on the outside and are therefore weather-proof.

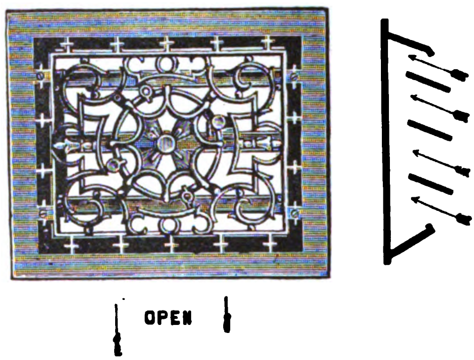

Fig. 247.—Louvre Ventilator.

Air Outlets.—When provision has to be made for the escape of vitiated air from a room other than by way of the chimney, the exits should be placed as near to the ceiling as possible.

Mica Flap Valves are occasionally fixed in the outer walls of bedrooms, so as to communicate directly with the open air, or they are fixed in the chimney.

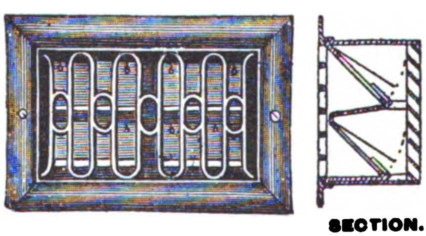

Fig. 248.—Mica Valve Outlet.

Fig. 248 shows one which may be fixed in the outer wall of a bedroom. The flaps of mica are hinged to open outwards. They permit air to pass from the room, but immediately close with a sharp crackling noise if the air current is reversed. The latter feature is liable to disturb the rest of nervous persons. The noise can be almost eliminated by having strips of felt on the surfaces with which the flaps come in contact. Silk flaps which are almost noiseless in action can be used instead of mica.

If the valve be inserted in a smoke flue, there is some risk of smoke and odours of an objectionable character gaining access to the room.

In one-storeyed buildings exits are generally arranged in the form of vertical tubes which pass through the ceiling and terminate just above the roof ridge. A cowl is placed over each exit, or several exhaust shafts may be gathered into one exit in the space between the ceiling and the roof.

Where two or more storeys require to be ventilated, the exhaust shafts from the lower rooms may be taken vertically through the upper rooms, or they may discharge horizontally from the ceiling line of each room into the open air. The former arrangement is preferable where it can be adopted.

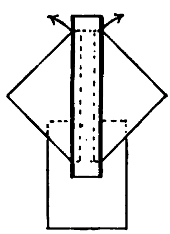

FIG. 249.—Torpedo Outlet.

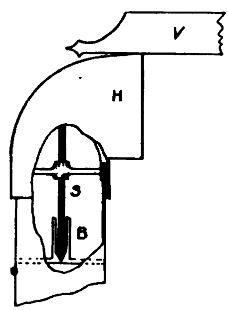

FIG. 250.—Hooded Swivel Outlet.

Various types of cowls are obtainable, certain of which are supposed to possess remarkable features whereby the vitiated air is extracted from the room, opposing factors notwithstanding.

Cowls should be weather-proof, simple in design, and so formed that a minimum obstruction is offered to the flow of air through them.

They should be constructed so as to prevent a reversal of the air current.

Fig. 249 shows the **Torpedo Cowl.** It is weather-proof, and is usually made of galvanised sheet-iron, copper, or zinc. The cowl has an aspirating effect on the air in the exhaust shaft when there is a wind.

Fig. 250 shows a **hooded swivel cowl** to which a wind vane is attached. The lower end of the spindle S works in an oil-cup

bearing B, which carries the hood H. The vane V causes the hooded outlet to assume a position with its opening in the direction in which the wind is blowing. An aspirating effect is thus obtained and down-draughts prevented.

Fig. 251 shows an **Archimedean screw ventilator.** The vertical blades cause the wheel W to revolve in a wind. The spindle of the spiral blade S is rotated and air is extracted through the exhaust shaft.

This device will not give good results when there is no wind. The screw S tends rather to impede the air under such

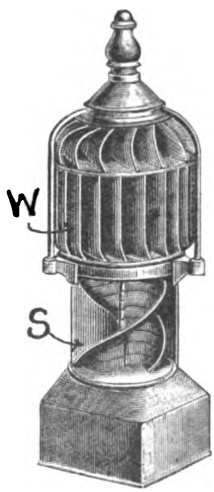

FIG. 251.—Archimedean Screw Outlet.

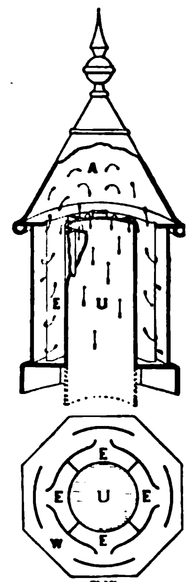

FIG. 252.—Barker's Extractor.

conditions, instead of assisting its escape. The whirring noise which it makes during high winds is also objectionable.

Fig. 252 shows the plan and section of a satisfactory form of ventilator suitable for large exit shafts. The tube U exhausts into the chamber A, whence the vitiated air passes into the four chambers marked E; from these it is aspirated by external air currents.

Heat is sometimes employed to aid natural ventilation. Common examples of its application are:—

1. **Bunsen Burners or Steam Coils** fixed in exhaust shafts.

2. **Special Stoves** burning oil, gas, coke, or coal fuel, and having chambers which communicate with the interior and exterior of the room. The incoming air is warmed by contact with the heated surfaces before entering the room.

3. **Specially formed Fire Grates**, such as Galton's (Fig. 253), which consists of a cast-iron air flue fixed at the back of the fire grate and continued vertically behind the smoke flue to a height of 8 or 9 ft. above floor-level. The lower end of the air flue is continued to the exterior face of the wall, and the upper end discharges into the room.

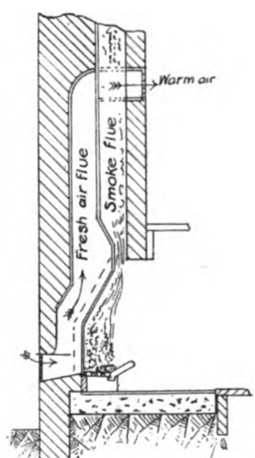

FIG. 253.—Galton's Grate.

4. **Ventilating Radiators**, as shown in Figs. 196 to 199.

The heat from a Bunsen flame or a steam coil fixed in an exit shaft raises the temperature of the escaping air, and thereby increases its velocity.

Where ceiling gaslights are used, the heat from them can be utilised instead of Bunsen flames or steam coils, by fixing the lights immediately beneath the exit shafts.

Where the incoming air is warmed by contact with heated surfaces, its velocity is increased, and in consequence a greater quantity of air passes through the inlets in a given time.

In the case of ventilating stoves and fire grates, the organic particles in the air become charred, owing to the high temperature of the heated surfaces, and impart an unpleasant odour to the air in the room. Moreover, if the cast-iron air chamber or flue become fractured, fumes from the fire will mingle with the fresh air as it enters the room.

Ventilating stoves are often used in hospitals. They are placed in the centres of the wards, and the smoke outlets communicate with flues laid beneath the floor. Fresh-air inlet tubes are laid separately or alongside the smoke flue, and are connected to the heating chambers. A quantity of radiant heat

is emitted from the outer surface of the stove, in addition to the heat imparted to the incoming air.

Fig. 254 shows one method of ventilating and warming a large room by natural means. A double system of air inlets is provided. A portion of the fresh air is admitted to the room through the ventilating radiators R R, etc., whilst a second portion enters through the short Tobin's tubes T. By this means the temperature of the air in the room may be regulated

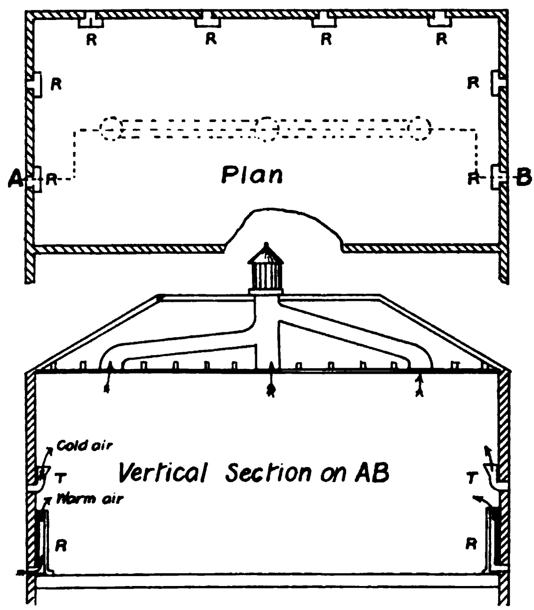

Fig. 254.—Natural Ventilation of One-storeyed Building.

to some extent by adjusting the baffle plates of the radiator and tube inlets.

Three exhaust shafts are provided in the ceiling. They are gathered in one exit shaft, which pierces the ridge of the roof and is surmounted by a suitable cowl.

Fig. 255 shows the application of the above system to a two-storeyed building.

The exit shafts of the lower room may commence in the centre of the room, and be continued under the floor and up the wall to the exhaust shafts from the upper room, as indicated at

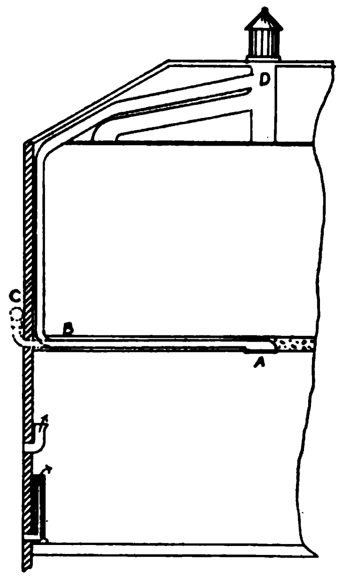

FIG. 255.—Natural Ventilation of Two-storeyed Building.

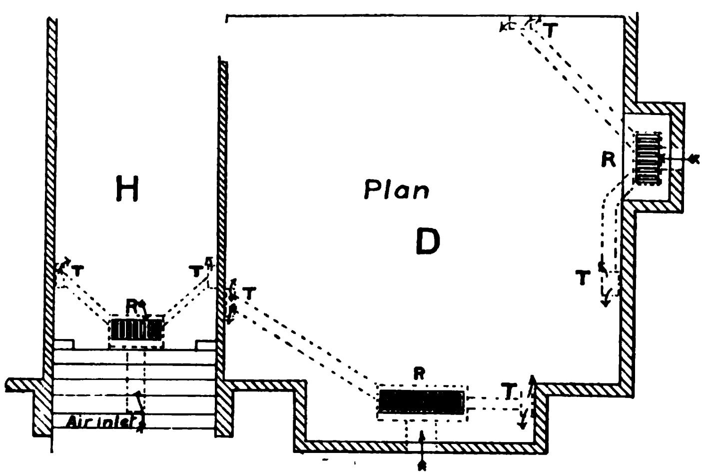

FIG. 256.—Use of Indirect Radiators in Ventilating a House.

A B D, or they may be taken through the wall, as at C, and have suitable cowls placed on their terminals.

If the tube A B is inconvenient, the exits may commence at the point marked B, but care should be taken to arrange their positions in relation to the inlets so that direct air currents between the two cannot occur.

In the case of reception-rooms, halls, and dining-rooms in private dwellings, indirect ventilating radiators are generally used. They are placed in chambers beneath the floor; the air supply being conveyed through special conduits from the outside wall to the various parts of the rooms.

The exit shafts that are provided in addition to the chimneys are difficult to arrange so that they will not be unsightly. Fig. 256 shows the plan of a portion of the ground floor of a large house. The hall H has a ventilating radiator placed beneath the floor of the entrance. Two warm-air tubes distribute the fresh air on each side of the hall. The room D is a comparatively large one, in which two ventilating radiators, R R, are placed. The warm air is distributed as evenly as possible by means of the tubes T T, etc.

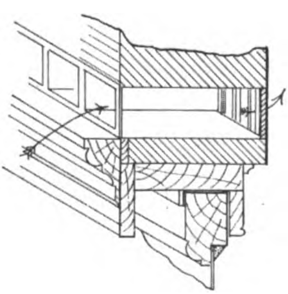

Fig. 257.—Air Exits in Walls of a Dining- or Drawing-room.

The exits may be arranged in the ceilings of the bay windows, and have special tubes fixed in the walls terminating above the roof; or lattice ventilators may be provided above the tops of the window frames, as shown in Fig. 257.

W.C. apartments require special treatment. Fixtures should be inserted which will secure the uninterrupted passage of a stream of air through the apartment. The opening of a window must not be relied upon for this purpose. The air should be admitted at floor-level, care being taken to prevent the incoming air from impinging against the porcelain w.c. basin, otherwise during frosty weather the water-content of the latter is liable to freeze and fracture the trap.

The exit may discharge horizontally through the outer wall

at ceiling-level, or a vertical tube discharging above the roof may be provided to prevent down-draughts.

Fig. 258 shows a simple arrangement of inlet and exits suitable for the purpose. A and B are alternative outlets, and C is the air inlet which passes beneath the floor-level and discharges from a side wall in order to prevent cold air from striking the w.c. basin.

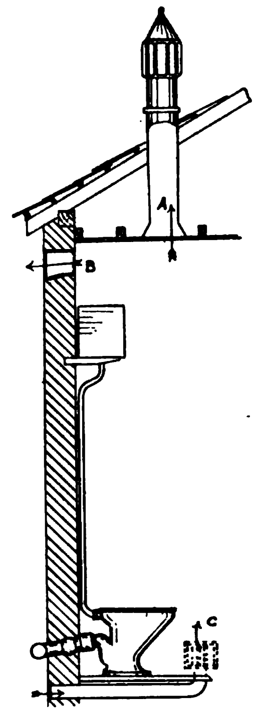

Fig. 258.—Ventilation of a W.C. Apartment.

Advantages of Natural Ventilation.—These consist chiefly of:—

1. Low cost of installation and maintenance.

2. The system can be applied to existing buildings without great difficulty.

3. The incoming air retains its invigorating properties.

The Defects of Natural Ventilation are:—

1. It is impossible to regulate the air supply to meet the various requirements. This defect is especially emphasised in the case of a building in which the air space per head is small.

2. The incoming air is invariably cold, and in winter-time is likely to cause inconvenience.

3. There is some risk of the air currents being reversed by the force of the wind. Inlets would then act as outlets and *vice versâ*.

4. During hot weather, if the outer air be still, there are no air currents in the rooms when a maximum air movement is desirable. Moreover, the air cannot be systematically cooled.

Mechanical Ventilation consists in using a mechanical device to change the air in a building.

There are three modes of mechanical ventilation.

1. Plenum system.

2. Vacuum system.

3. Combined plenum and vacuum.

In No. 1 the air is forced to various parts of the building through special conduits. An air-pressure slightly greater than that of the atmosphere is maintained in the rooms.

In No. 2 the vitiated air is extracted from the building. Special air inlets are generally provided.

No. 3 consists of a combination of Nos. 1 and 2. Vitiated air is extracted through special outlets, and fresh air is forced into the rooms by mechanical devices.

Jets of Water or Steam are sometimes used to provide the motive force by which air is extracted from a room, but they are not suitable for forcing air into a room. They are expensive to maintain, and generally are not efficient.

Fans and Propellers are the most suitable appliances for forcing air into or extracting it from a building. Although

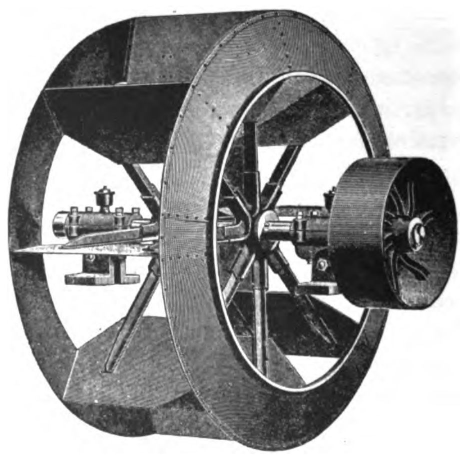

FIG. 259.—Fan-wheel.

the two terms are often used indiscriminately, they refer to distinct types of rotary machines.

Fig. 259 shows a "fan-wheel" with the casing removed. It resembles the paddle wheel sometimes used for propelling ships, and is useful for driving air against a moderate amount of resistance.

Fig. 260 shows one form of propeller with pulley wheel attached. It is suitable for use in positions where the air resistance on the discharge side is slight and the inlet and outlet are free from obstruction.

For exhausting air from buildings ventilated on the "vacuum" principle, it is a better appliance than the fan-wheel, but the latter gives better results where the air has to be forced through conduits, as in the plenum system.

The "disc wheel" is a modification of the "propeller." It consists of discs or blades attached to spokes radiating from a central shaft. The discs can be adjusted to obtain the angle at which the wheel develops the maximum efficiency.

The vacuum system of ventilation is the cheapest to install, and is suitable for mills, workshops, and factories. Each room requires the services of one or more propellers, which are usually fixed near to the ceilings in apertures in the outer walls.

If the rooms are wide and long, propellers will be required on each side of the building.

Special air inlets are usually provided either in the form of hopper windows, Tobin's tubes, or galvanised sheet-iron air ducts laid beneath the floor from the outer walls to the centre of the room. The latter is the most efficient arrangement. Several vertical branch tubes are attached to each horizontal tube in order to distribute the fresh air evenly. The sizes of the branch tubes should be proportioned so that those farthest from the outer wall will receive an adequate supply of air.

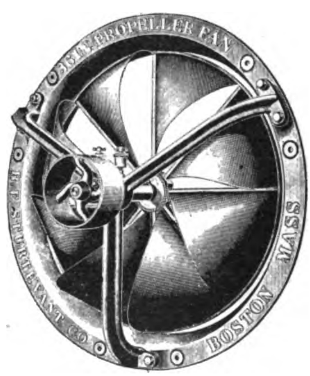

Fig. 260.—Air Propeller.

The incoming air may be warmed by causing it to pass over heated pipes fixed in the air tubes.

In this system the inlets discharge the air from 5 to 6 ft. above the floor, and the propellers are fixed at the highest points in the rooms.

For a large building consisting of a number of rooms, the plenum system gives better results than the vacuum system.

For buildings of moderate size one fan is usually sufficient, but in the case of large buildings two fans are necessary.

The fans are situated in the basements. They draw air

through special inlet ducts, and force it through distributing ducts formed in the floors and walls of the building.

Combined Heating and Ventilation can be accomplished economically by use of the plenum system. Instead of warming the individual rooms by pipe or radiator systems, the temperature of the fresh air is raised to 75° or 80° F. by heaters placed in the inlet or outlet ducts of the fan. The air enters the rooms at a high temperature, and by cooling from 75° to 60° F. imparts sufficient heat to compensate for that lost through the walls, windows, floors, etc.

If exhaust steam in sufficient quantity be available, its latent heat can be utilised by coupling the heater tubes to a vacuum pump and passing the steam through them.

This mode is adopted at the Municipal School of Technology, Manchester. The heat obtained from the exhaust steam from the school electric generating plant is sufficient to maintain the internal temperature of this colossal building at 60° F. during the coldest day in winter.

The Double-Duct System consists of a duplicate set of distributing conduits, one carrying cold air and the other hot air.

The Single-Duct System has one set of conduits which carry either hot or cold air, according to requirements.

In the latter case it is difficult to regulate the temperature of the individual rooms. The rooms near the fans receive air at a higher temperature than those that are more remote. This defect can only be remedied by varying the quantity of radiating surface in the heaters, and regulating the volume of air delivered into the various rooms.

If it is necessary to reduce the quantity of air delivered into a room so that a desired temperature may be obtained, mechanical ventilation on this principle fails to achieve its object, namely, that of supplying a definite volume of air irrespective of atmospheric conditions.

This defect is entirely eradicated by using the double-duct system.

The outlet of the fan casing has a damper or baffle plate which divides the stream of air into two portions, one of which enters the cold-air duct, and the other passes through the heaters to the warm-air duct.

The relative quantities of air entering the two ducts can be adjusted by raising or lowering the damper. In very cold weather the whole of the air from the fan may be passed through the heaters by raising the damper to the maximum extent. A portion of Fig. 264 shows a fan with heater and connections for cold and warm air conduits.

The air enters the centre of the fan-wheel and is discharged into the duct leading to the heaters. The damper regulates the quantities delivered into each duct.

Generally, the cold-air duct has only half the capacity of the warm-air duct.

Mixing Dampers are necessary in this system. They are fixed at the points where the air enters the rooms. Various types are obtainable, but in each case the damper must be so constructed, that the relative quantities of hot and cold air may be varied without affecting the total quantity delivered.

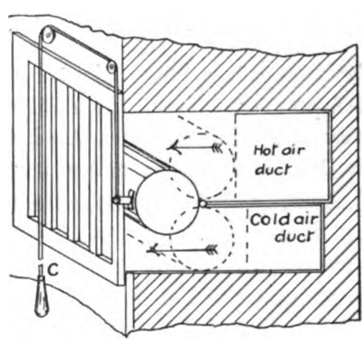

FIG. 261.—Cylinder Mixing Damper for Air Inlet.

Fig. 261 shows a simple form of damper consisting of a cylinder pivoted to the midrib dividing the hot and cold inlet ducts. The damper is raised or lowered by the chain C. This is a very effective mode of regulating the temperature in the various rooms. The quantities of hot and cold air may be adjusted and intimately mixed to suit varying requirements.

Downward Ventilation.—In the "natural" system of ventilation the vitiated air escapes at the high portions of the rooms, and fresh air is admitted at the lower portions. This arrangement also obtains in certain mechanical systems. It is contended by the advocates of downward ventilation that greater efficiency is obtained by delivering the air above the breathing line into the room, and providing exits at or near the floor. The inlets are fixed at a height of from 8 to 12 ft. above the floors, and are made to deliver the stream of air horizontally.

The fresh air has a higher temperature than that of the room, and, entering at a velocity of from 200 to 300 ft. per minute, it rises, and tends to scour all the upper portion of the room, thus preventing the formation of "pockets" of dead air. It is also contended that the products of respiration, excretions from the skin, and dust which tends to rise from the floor, are carried downwards by the air currents moving towards the exits.

With regard to the respiratory impurities, it is doubtful whether this contention can be sustained. Assuming that in a room 12 ft. high the air is changed five times per hour, if the stratum of fresh air be equally distributed over the higher portions of the room, it will descend towards the exit at the rate of $\frac{60}{12 \times 5} = 1$ ft. per minute—a velocity which is almost imperceptible. The air that emanates from the lungs has a temperature of 98° F., which is at the least 20° F. above that of the fresh air delivered through the inlets. Local air currents will be set up in many parts of the room, the expired air ascending and mingling with the fresh air.

If gas or oil be used for artificial lighting the products of combustion will mingle with the fresh air and be brought down past the breathing line.

With electric lighting this defect is entirely obviated.

The exits may exhaust directly into the open air through outside walls; but in a building possessing a system of corridors the exits may exhaust into these; one or more common outlets, usually the stairways or open windows in the corridors, are available through which the vitiated air may pass to the outside of the building.

The fans are generally fixed in the basement or sub-basement.

The intake duct usually extends from the fan to the top of the building. The openings in this duct through which the air passes to the fan are situated at different heights and are controlled by dampers. By this arrangement the air may be taken from the clearest stratum.

This is an important point in large towns and cities, as the smoke pall accumulates at varying levels according to atmospheric conditions. The distributing ducts in new build-

ings form an integral part of the original design, and are situated chiefly in the corridor floors and in the inside walls of the rooms. They are made of concrete, brick, or galvanised sheet-iron. The latter offers a smooth surface and is in many ways more serviceable than either brick or concrete.

In the application of a mechanical system of ventilation to old buildings, galvanised sheet-iron is invariably used for the distributing ducts. Great care is necessary when arranging the positions of the air tubes, or unsightly results will be obtained.

Inside walls should be utilised as far as possible. Where it is necessary to fix a tube against an outer wall, a layer of slag wool should be inserted between the wall and the tube to minimise the loss of heat.

All bends must be formed to a large radius, and junctions must be of the curved pattern.

Circular tubes offer less resistance than rectangular tubes of the same size, but the latter can usually be accommodated more readily in hidden positions than the former.

In workshops, mills, and factories, circular tubes of galvanised sheet-iron are generally used. They are cheap and easily fixed, and with ordinary care will last a long time.

The velocity at which air travels through the distributing ducts varies with different systems. It is considered inadvisable to have velocities higher than 360 ft. per minute. Satisfactory results are obtained by velocities of from 180 to 250 ft. per minute. The velocity of the air in a duct or through an opening can be determined in several ways.

Reasonably accurate results are obtained by the use of an air meter. This appliance consists of a delicate disc wheel attached to a spindle which is connected to a recording dial by geared wheels. All the parts are finely adjusted and balanced, so that friction is reduced to a minimum. A clutch is provided by which the recording gear can be put in or out of action.

Fig. 262 shows a view of one form of **anemometer or air meter.**

The average of six readings, each of one minute duration, is usually taken.

When taking readings of the velocity of air through an aperture or inlet, the anemometer should be held in the front of

the centre of the opening at a distance of 5 or 6 ins. from the same. The operator's body, arm, or other obstruction must be entirely clear of the air stream.

The wheel should be allowed to "run free" for about fifteen or twenty seconds. The recording gear clutch should then be pushed over at the same instant that the time is taken. At the end of one minute the gear must be thrown out of action and the reading taken. This operation is repeated six times in all, when the total movement of the air during six minutes will

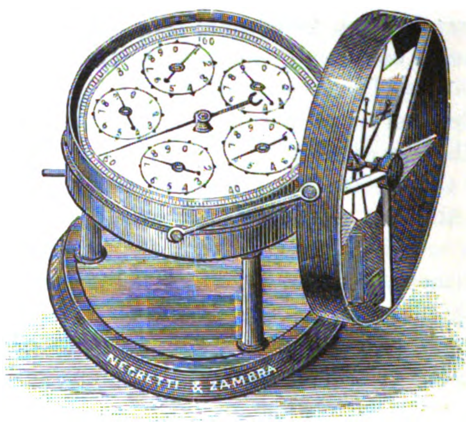

FIG. 262.—Anemometer.

be recorded on the dial. The average velocity per minute is obtained by dividing this by six.

A milled-edged wheel fixed at the periphery of the dial is rotated to bring the indicators to zero when the recording gear is out of action.

Screens are used in conjunction with many plenum systems. The air of cities and manufacturing towns contains comparatively large quantities of dust, soot, and other solids, in a finely divided state. These solids are liable to cause irritation of the mucous lining of the air passages in the nose, throat, and lungs; also dust is deposited in objectionable quantity about rooms, if means be not taken to remove a portion of it from the air before the latter is delivered into the building.

Screens used for this purpose are of the following types:—

1*st*. Canvas screens, either fixed or revolving.

2nd. Coke screens.

3rd. Galvanised corrugated iron sheets, known as the "mist screen," or "wet filter."

Fixed canvas screens consist of large wooden frames covered with coarse canvas and fixed in zigzag fashion in the "intake," as shown in Fig. 263.

A large quantity of solid matter is arrested. The screens require to be cleaned at least once per week.

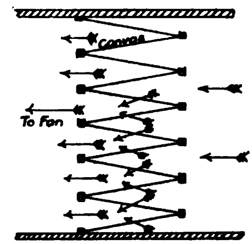

FIG. 263.—Fixed Canvas Screens.

Attempts have been made to wash the screens by intermittent discharges from suitably placed sparge pipes, but without success. The water fills the smaller spaces between the fibres in the canvas and materially reduces the quantity of air passing through; also, the solids are washed into the canvas and tend to make it impervious to the passage of air.

Movable canvas screens usually consist of an endless band of canvas stretched over two rotating rollers and entirely filling the intake at a point near to the fan. The lower roller revolves in a trough of water, thereby keeping the canvas moist and tending to deposit or wash off the impurities. A sparge pipe is fixed so that a stream of water can be directed, either constantly or intermittently, over the screen.

The quantity of solid matter arrested in this screen is considerable, and necessitates the frequent renewal of the canvas.

During a foggy day the flow of air will be almost stopped by accumulations on the screen which cannot be removed by the fixed washers.

Coke Screens consist of baskets or cradles filled with pieces of coke breeze of from 2 to 4 ins. cube; they entirely fill the intake for a length of from 1 ft. 6 ins. to 2 ft. 6 ins. Water from fixed sprays is discharged constantly or intermittently over the coke. The solids in the air are arrested by the moist, rough surfaces of the coke. Periodic renewals of the coke are necessary to prevent the filters from becoming choked, for frequent discharges from the sprayers will not entirely remove the deposit.

The disused coke can be utilised as boiler fuel, thus avoiding waste.

The Mist Screen or Wet Filter of the Sturtevant pattern consists of sheets of galvanised corrugated iron fixed on edge at an angle of 45° in the intake. The sheets are placed ¾ in. apart, and are from 2 ft. to 3 ft. deep.

Two or more fine sprayers or water atomisers are placed above each filter. Under a working pressure of 20 lbs. per square inch and over, the water which passes through them is divided into very fine particles resembling mist.

Some of the finer solids in the air are engaged by these particles, and are deposited on the sides of the corrugated sheets. The corrugations cause the air stream to change direction many times during its passage through the filter. The air travelling at a high velocity strikes the surfaces of the sheets with some force, and the dust-laden particles of moisture are arrested and eventually drain into a specially formed channel, from which they may be discharged into a drain or into a sump or well.

It is estimated that from 50 per cent. to 75 per cent. of the solids are removed from the air by this filter.

It is necessary to place a small heater some distance above the filter to prevent it from freezing and blocking the air passage during frosty weather.

In some systems a by-pass doorway is provided through which a sufficient quantity of warm air from the interior of the building is admitted to the inlet duct at a point above the filter, to raise the temperature of the fresh air above freezing-point.

This arrangement is not satisfactory. The delivery of vitiated air into the fresh-air duct is against the first principles of ventilation. Moreover, it leads to abuse of the system by the attendant, owing to the ease with which the dampers in the fresh-air duct can be closed, and the vitiated air circulated through the building many times.

The wet filter which is in use at the Manchester Municipal School of Technology arrests on an average over 10 lbs. of dry solids per working day of twelve hours.

The following is a list of some of the constituents of the solids obtained from Manchester air:[1]—

[1] By the kind permission of Prof. E Knecht, Ph.D., M.Sc. (Tech.).

Sludge, which had collected beneath the screens during the fog that occurred in the week ending November 26, 1904, appeared in the moist state, of an intense black colour resembling soot. On drying, it became grey, and left on ignition a very high percentage of mineral matter (75 per cent. of the dry substance).

It contained small quantities of hydrocarbons and phenolic constituents. The hydrocarbon oils were similar to those obtained from chimney soot, and are soluble in benzene with a green fluorescence.

Screen Wash-water.—During the fog of December 22, 1904, the two fans were reduced between 4.15 and 5.15 P.M. to three-quarter speed, so that 300,000 cub. ft. of air passed through the screens per minute. The water supplied to the atomisers amounted to 240 galls. during this period. One gallon of the water was collected and examined. It appeared to be a black, greasy-looking liquid, which on filtering was found to contain but a small quantity of black solids in suspension. The filtrate, which still retained its greasy appearance, was of a slightly yellow colour, and showed a distinctly acid reaction, due to the presence of sulphuric acid. The acidity was equivalent to 6·2 grs. sulphuric acid per gallon—this represents a total of 3½ oz. of acid taken out of the air during the hour. The total solids in this wash-water, when dried at 100° C., represented a dark brown hygroscopic mass, and amounted to 91·7 grs. per gallon. This residue was found to contain a considerable quantity of ferrous iron, some ferric iron, ammonia, lime, magnesia, a trace of arsenic, and sulphuric and hydrochloric acids.

The Screen Soot gave 75·01 per cent. inorganic matter.

Sill soot gave 45·78 per cent. inorganic matter.

Flue soot gave 76·22 per cent. inorganic matter.

Fig. 264 shows a plan and sections of a wet filter with atomisers or sprayers. A heater may be provided above the sprays to prevent the water from freezing during frosty weather.

Heaters usually consist of batteries of pipes of small diameter arranged in such a manner that the maximum surface is exposed to the air currents. From five to ten batteries are used, each of which is controlled separately. By this arrange-

ment the temperature of the air can be regulated to suit varying requirements.

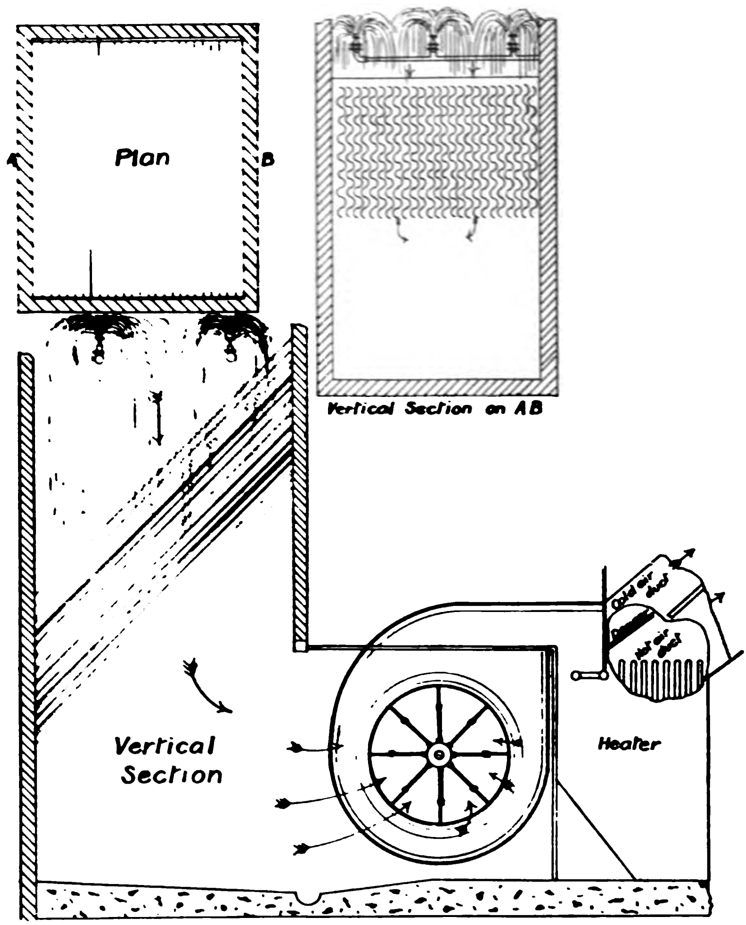

FIG. 264.—Plan and Sections of "Wet" Filter or "Mist" Screen.

Humidity.—The quantity of water-vapour which a unit volume of air contains has some influence upon the comfort of the occupants of a room.

In extremes of heat and cold, the maximum degree of comfort is experienced with comparatively dry air. Temperatures above 200° F. can be withstood for long periods if the air be dry, but if the relative humidity be high, evaporation of

perspiration from the cutaneous tissue goes on more slowly. In consequence, the body temperature increases and causes a derangement of the functions of the internal organs.

For air temperatures between 55° and 70° F. to be borne comfortably, the humidity should not exceed 75 per cent. nor fall below 50 per cent. of saturation. In the latter case the skin becomes harsh and dry, and the mucous lining of the air passages to the lungs is adversely affected.

A high degree of humidity causes an oppressive feeling of closeness due to restricted evaporation from the skin.

The adjusting of the humidity of the air in mechanical systems of ventilation is a difficult matter.

In winter the air is admitted to the fans at a low temperature, and consequently the quantity of water-vapour per unit volume will be small.

Assuming that the air is saturated, and has a temperature of 41° F. when it enters the fan, and that it is raised to 75° F. during its passage through the heaters, the relative humidity will be reduced from 100 per cent. to 33 per cent. approximately.

For 1 cub. ft. of saturated air at 41° F. contains 3 grs. of water-vapour.

And 1 cub. ft. of saturated air at 75° F. contains 9 grs. of water-vapour.

$\therefore \quad 3 : 9 :: x : 100 = 33$ per cent. (approx.).

(The increase in volume of the air owing to expansion is not taken into account.)

Where wet filters are used, the humidity can be adjusted to some extent, but periodic observations and readings of a hygrometer placed in the delivery duct are essential to achieve successful results.

It should also be remembered that a considerable quantity of water-vapour emanates from the lungs. This will increase the degree of humidity of the air.

With natural systems of ventilation troughs of water are exposed in the rooms, usually on one or more radiators. The troughs require to be cleaned daily to prevent them from becoming objectionable.

Mechanical systems of ventilation possess the following advantages:—

1. A definite quantity of air can be delivered into a building irrespective of the condition of the atmosphere or structural considerations.
2. The temperature of the air can be varied to suit the requirements of the occupants and of the atmosphere.
3. A large proportion of the solids can be extracted from the air.
4. The degree of humidity of the air can be varied to some extent.

With regard to advantage No. 2, arrangements can be made for reducing the temperature of the air during hot weather, by placing in the inlet duct, ice, or pipes connected with a refrigerating plant.

The disadvantages of mechanical ventilation are:—

1. The cost of installing and maintaining the systems is relatively high.
2. The air which has passed through the fans is not so invigorating as the air supplied to rooms ventilated on the "natural" principle.

The latter factor is noticed by persons during the early portion of their occupancy of a mechanically ventilated building. A feeling of lassitude is experienced which requires a strong effort to control and to subdue.

Efforts have been made to counteract this effect by discharging small quantities of electrically produced ozone into the delivery ducts, but the system has not proved successful.

Hot-air Apparatus for ventilating and warming buildings consists of a stove or fire box in which a battery of cast-iron tubes is placed. The air passes through these tubes and is warmed before delivery into the building.

The air inlets are usually situated near to the floor, and the exits are placed in the ceilings or roofs.

The chief disadvantages of this system are:—

1. The products of combustion may enter the building owing to defective joints or fractured pipes in the stove.
2. The organic particles of dust are charred by contact with the heated surfaces, and give rise to unpleasant smells.
3. The invigorating properties of the air are impaired.
4. The quantity of air delivered is not definite, and no means are available for readily adjusting the temperature.

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